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Growth Habit of the Rice Plant in the Tropics and Its Effect on Nitrogen Response

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Part I

Growth Habit and Nutrient Uptake of the Rice Plant in the Tropics

Determination of optimum cultural practices to obtain consistent high yields of a crop depends upon knowledge and understanding of the growth processes of that crop.

The growth processes of rice plants under a given environmental condition differ with variety. The growth processes of a variety differ with different sets of environmental conditions. Varietal characteristics and environmental conditions interact in complicated ways. These interactions make understanding of the growth processes and determining optimum cultivation methods difficult.

This report attempts to describe the general patterns of the growth processes of typical tropical rice varieties when grown in the tropics in different seasons and with adequate nutrients and water.

Materials and Methods

Varieties

The International Rice Research Institute is located at Los Baños, Laguna, Philippines, 14°10'N latitude at an elevation of 28 meters. Farmers in the vicinity cultivate *indica* varieties, some being seasonal and others non-seasonal. Experimental results at the Institute indicate that some of the *japonicas* from Taiwan ('ponlai' or 'horai' types) are promising because of high and stable yields.

Three varieties: Peta, a weakly photosensitive *indica;* BPI-76, a highly photosensitive *indica;* and Tainan-3, a *japonica* from Taiwan, were used in this study. Tainan-3 is short, has a moderate tillering activity, and has erect, dark green leaves. Peta is tall, active-tillering, and leafy. BPI-76 is moderate in tillering, thick-strawed, and has erect leaves (Figs. 1.1 and 1.2).

The response of these varieties to photoperiodic treatments under greenhouse conditions (Fig. 1.3) indicates that, within the day length fluctuations at Los Baños (from 11 to 13 hours), the maximum changes in duration associated with day length would be about 0, 30, and 90 days for Tainan-3, Peta, and BPI-76, respectively.

Planting Seasons

On farms near the Institute, farmers usually plant in June or July when the monsoon starts. They call this the "rainy season crop." Farmers with irrigation facilities plant a second rice crop during the period November-January; they call this the "dry season crop."

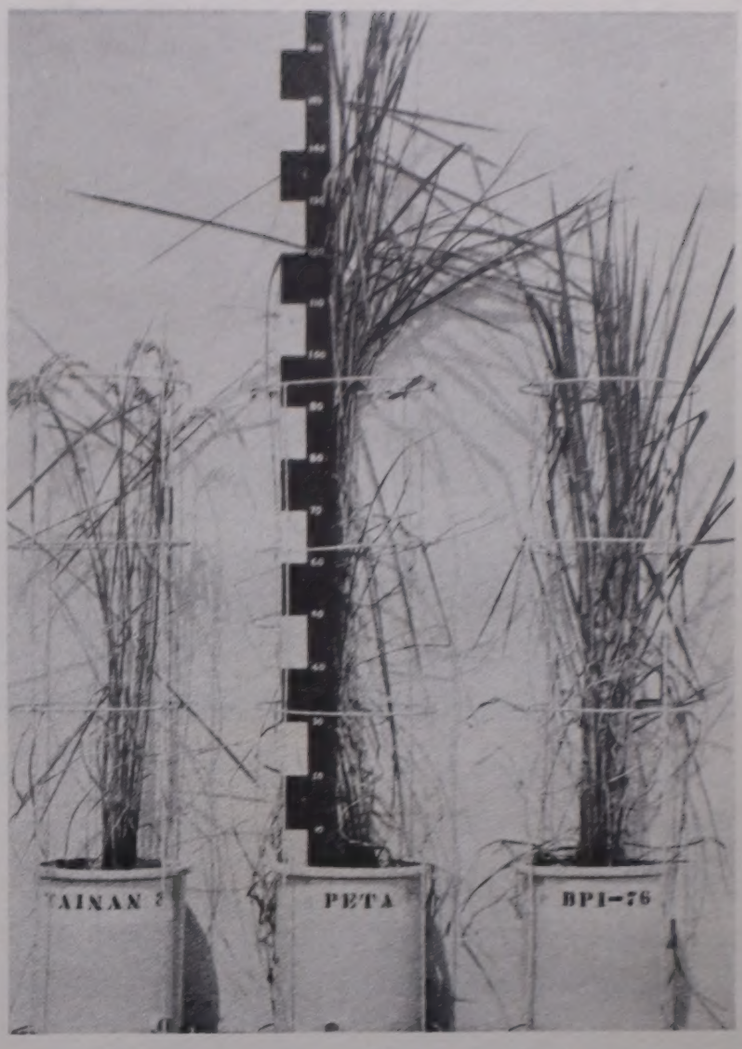


Figure 1.1. Characteristics of Tainan-3, Peta, and BPI-76 plants (planted May 1963) at the time Tainan-3 was harvested.

After considering the farmer's situation and the characteristics of the rice seasons, four dates of planting were chosen. The dates of sowing were March 15, 1963; May 3, July 16, and October 26, 1962. The March planting may be considered as an off-season crop. The May and July plantings were early and late rainy season crops, and the October planting provided a dry season crop.

Cultivation Method

A single method, which is standard at the Institute, was used for all varieties and in all seasons. After 2 days of soaking, seeds were sown on a wet seedbed with no fertilizer. Twenty-five days after sowing, the seedlings were uprooted, leaves were trimmed 15 cm from the base, and the seedlings transplanted to the main field at a distance of 30 x 30 cm with one plant per hill. These nitrogen levels and spacings obviously were not optimum for each variety in each season; consequently, yields reported here probably are not as high as

Figure 1.2. Plants of Tainan-3, Peta, and BPI-76 (from left) one month after transplanting in June, 1962, at 30 x 30 cm.

might be possible if practices were adjusted to fit varietal requirements.

The main field was prepared dry with a plow pulled by a carabao. About 5 days later, the plot was irrigated, puddled with a harrow, and then leveled. One day before transplanting, ammonium sulfate, triphos, and muriate of potash were applied at the rate of 40 kg/ha of N, 17 kg/ha of P, and 33 kg/ha of K, and the soil again puddled.

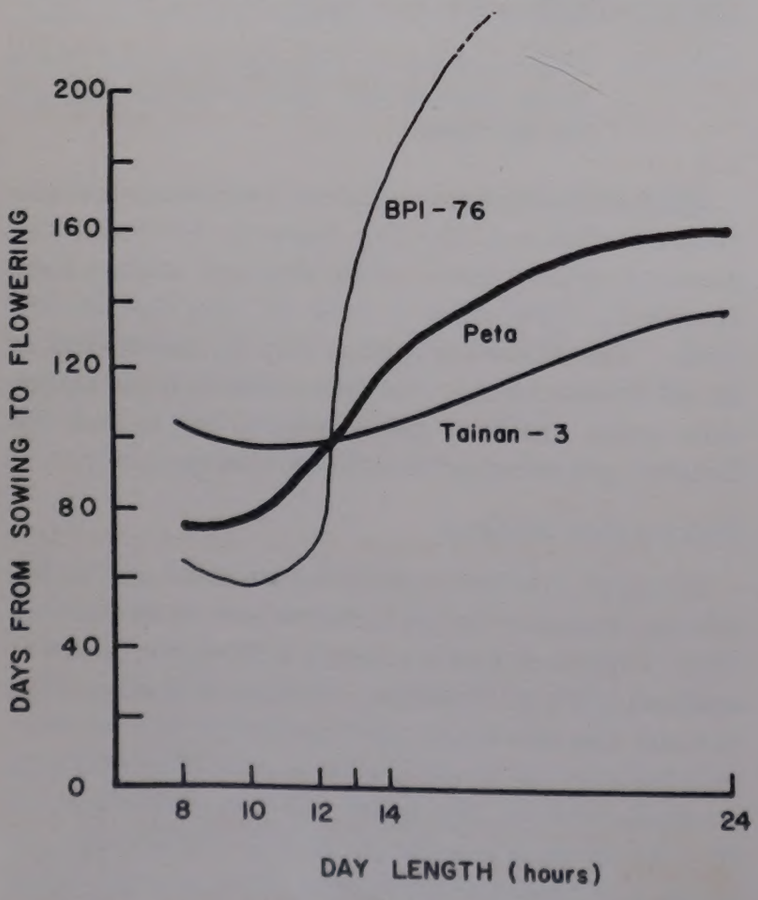


Figure 1.3. Response to photoperiod of Tainan-3, Peta, and BPI-76 (IRRI annual report, 1963).

After transplanting, the field was kept flooded until about the dough stage; then irrigation was stopped. Insecticides were applied weekly as sprays, and plots were weeded with rotary weeders or by hand when necessary. Whenever there was danger of lodging, four hills were tied together to keep the plants standing.

Samplings and Analysis

Sample plants were taken at random from the field every other week. The samples were: At planting, 100 plants; 2 weeks after transplanting, 50 plants; and at the later stages of growth, 10 plants. After data were collected on height and tiller number, the roots were discarded; the plants were washed thoroughly; active straw, dead leaves and panicles were separated, and these parts were dried in a forced draft oven at 70°C for 1 or 2 days. The samples were weighed, ground, and a small portion of the ground samples were kept in bottles for analysis.

At each sampling period, another five plants were used to obtain data on leaf length, percentages of nitrogen and starch of each leaf, and information on internode number and elongation.

The light transmission ratio was measured at each sampling period. The light intensity at the

top of the plot and at ground level, at a point equidistant from four hills was measured with a Toshiba light meter. The intensity at the base was expressed as a percentage of that at the top.

Climatic Conditions

Fig. 1.4 shows data on day length, air temperature, rainfall, and percentage of sunshine hours collected by the weather station of the College of Agriculture, University of the Philippines, adjacent to the Institute.

At Los Baños, the southwest monsoon prevails from June to September, the northeast monsoon from December to January, and the trade winds from March to April. The periods between these seasons are transitional. It is dry from January through April, and the rains begin by the middle of May. July to August are the wettest months, but October-November and May-June also are wet periods. In April and May, the temperature is relatively high (28°C mean), and during the rainy season, it is relatively constant (26-27°C). It then declines to about 25°C, where it remains from November to February (Uichanco, 1959).

At the time of the March planting, the climate was characterized by medium temperature, no rain, abundant sunshine, and medium day length. With the growth of the plants, the temperature rose and the day length gradually increased. The rainless condition continued for a long period. The ear-initiation of Tainan-3 and Peta took place when the day length was longest and after the rains had started. During ripening, there were occasional rains. In the case of BPI-76, ear-initiation took place when the day length was shorter and when rains were more frequent.

The May planting coincided with the beginning of the rainy season when the temperature was high and the day length long. After transplanting, the day length became progressively shorter and the temperature was almost constant. There were occasional heavy rains. Heavy rainfall occurred during the ear-development of Tainan-3 and during the ripening of Peta.

The July planting occurred during the rainy season when the day length had begun to shorten. It rained heavily during the tillering stage and again during the ripening stage of all varieties.

The October planting occurred near the end of the rainy season. After transplanting, there was virtually no rain and the day length was shortest. The temperature was low. There was a comparatively high percentage of sunshine hours during the ripening phase.

Growth Phases and Their Duration

Growth Phases

Height, tiller number, and dry weight of straw, dead leaves and panicles of Peta in the May planting are plotted against the number of weeks after transplanting (Fig. 1.5).

After transplanting, height increased and reached a maximum at the flowering stage. The number of tillers per hill increased with growth, reached a maximum, then decreased. Dry weight of straw increased with growth, reaching a maximum at the flowering stage and then decreasing. Some of the lower leaves started to die after the maximum tiller number stage, and the amount of dead leaves increased with growth. The dry weight of panicles increased quickly after flowering, and continued increasing to the end of growth.

With some varieties two peaks of active dry weight increase have been reported. One is at tillering and the other is at later stages of growth (Tanaka, Patnaik, and Abichandani, 1959; Chiu, Lian, and Hsu, 1961). This tendency was observed in BPI-76 in the March and May plantings when the growth duration was extremely long.

From this type of growth pattern, the growth process can be divided into four phases: Active-vegetative, vegetative-lag, reproductive, and ripening phases.

1. **Active-vegetative phase** (from transplanting to the maximum tiller number stage). During this phase, the tiller number, height, and straw weight increase.

2. **Vegetative-lag phase** (from the maximum tiller number stage to the ear-initiation stage). The tiller number decreases. The increase in height and in straw weight continues but not as rapidly as before.

3. **Reproductive phase** (from the ear-initiation stage to the flowering stage). Ear-primordia develop; height and straw weight increase rapidly.

4. **Ripening phase** (from the flowering stage to harvest). Panicle weight increases actively; straw weight decreases.

Duration from Sowing to Harvest

In Tainan-3 the seasonal variation in the total growth duration was 14 days (Table 1.1). The duration of the crop planted in March was shortest and that planted in October was longest.

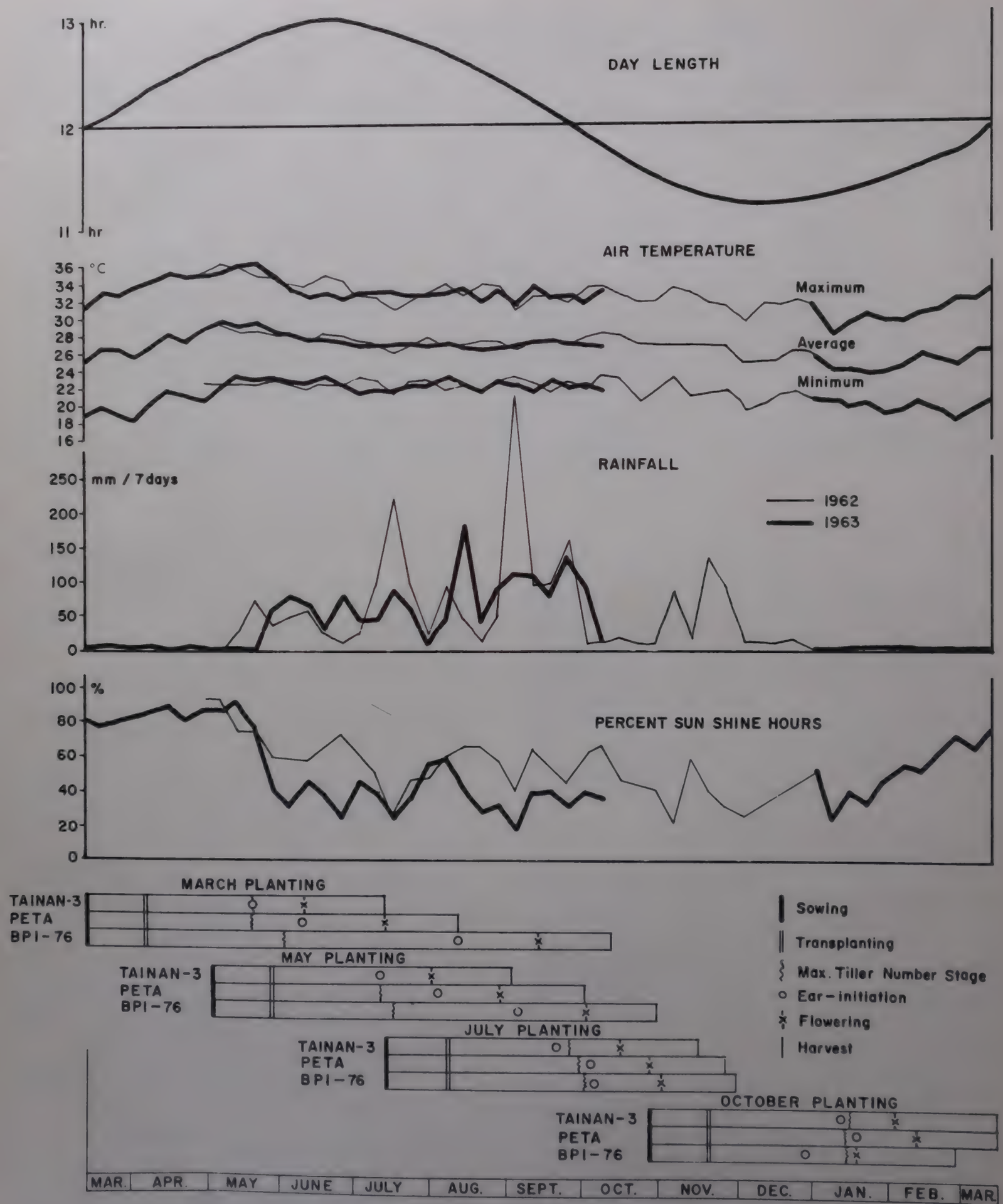


Figure 1.4. Growth pattern of Tainan-3, Peta, and BPI-76 in different seasons and weather conditions.

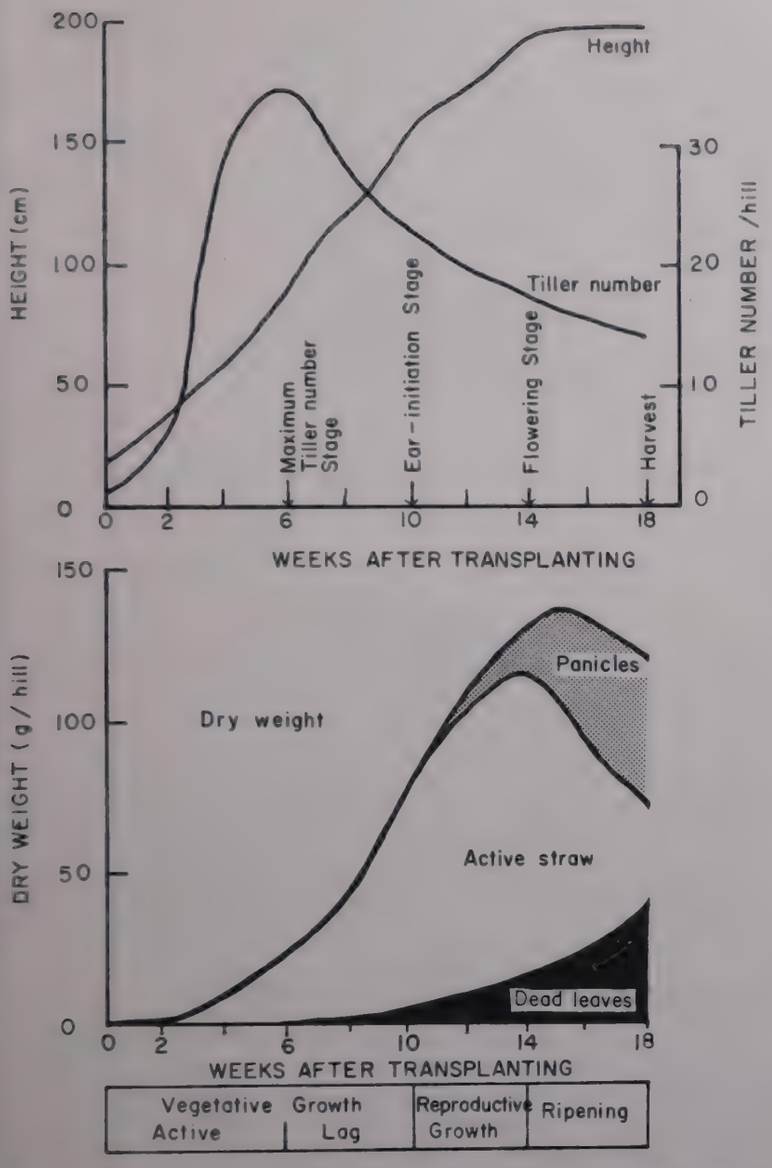


Figure 1.5. Growth pattern of Peta planted at IRRI, May, 1963.

Tainan-3 is non-sensitive to photoperiod. The seasonal changes in duration resulted from differences in temperature; that is, the crop planted in October developed during the coolest part of the year and the March crop grew during the hottest period. The seasonal change in the growth duration was small as Tainan-3 is a "non-seasonal" variety with a growth duration of 125-135 days.

In Peta, the duration of the crop planted in March and of that planted in July differed by 15 days. The change in growth duration among seasons was the reverse of that of Tainan-3 – the duration of the crop planted in March was longest and that planted in October was shortest. Peta is weakly sensitive to photoperiod. Differences in day length caused the difference in duration among seasons; however, the effect of temperature somewhat cancelled the effect of day length. The duration of Peta was fairly constant throughout the year; hence, the variety is considered "non-seasonal," with a growth duration of 135-150 days.

For BPI-76, the duration of the crop planted in March was longer by 90 days than that planted in October, largely because this variety is strongly sensitive to photoperiod. In the rainy season, the duration of BPI-76 is long; in the dry season it is short.

Table 1.1. Duration in Days, Sowing to Harvest, of Tainan-3, Peta, and BPI-76 Grown in Four Seasons, IRRI, 1962-1963.

Date planted	Days from sowing to harvest		
	Tainan-3	Peta	BPI-76
March 15	123	150	212
May 3	123	146	178
July 16	125	135	136
Oct. 26	137	137	122

Duration of Each Growth Phase

The duration of the active-vegetative phase was almost the same for all varieties. It was shorter for the March planting than for the October planting, but the difference was small (Table 1.2).

The duration of the reproductive phase was fairly constant (22-24 days), regardless of season and variety.

The duration of the ripening phase was slightly longer in Tainan-3 than in the other varieties. It was longer for the crop planted in October than for others; but the differences were small.

The difference in the duration from sowing to harvest resulted mainly from variations in the vegetative-lag phase. The vegetative-lag phase was longer when the total duration was longer. With 130 days total duration, there was almost no vegetative-lag phase. When the total duration is shorter than 130 days, the active-vegetative and the reproductive phases overlap.

The duration of the active-vegetative phase seems to be a function of the amount of available nitrogen. With constant nitrogen, the duration of the active-vegetative phase is almost constant. The time of ear-initiation primarily is a function of day length, and to a small extent, of temperature. Therefore, if cultural practices are held constant, the duration of the vegetative-lag phase varies with day length and temperature as well as with the photo- and thermo-sensitivity of the variety.

Table 1.2. Number of Days Required for Four Successive Growth Stages of Three Varieties in Four Seasons, IRRI, 1962-1963.

Variety	Date planted	Sowing to transplanting	Transplanting to maximum tiller number	Maximum tiller number stage to ear-initiation	Ear-initiation to flowering	Flowering to harvest
Tainan-3	March 15	25	42	0	22	34
	May 3	25	42	0	23	33
	July 16	25	60	-14	20	34
	Oct. 26	25	70	-19	22	39
Peta	March 15	25	42	28	25	30
	May 3	25	42	27	22	30
	July 16	25	50	10	22	28
	Oct. 26	25	50	10	22	30
BPI-76	March 15	25	50	84	25	27
	May 3	25	50	50	26	27
	July 16	25	56	- 3	24	28
	Oct. 26	25	56	-21	24	40

Grain and Straw Production

Grain Production per Crop

The grain yield of Tainan-3 was fairly high, and the variation among seasons was small (Table 1.3). This variety is non-seasonal in duration and produces more or less the same yield in any season.

The yield of October-planted Peta was high (6.04 tons/ha). In the other seasons, it was 3-4 tons/ha. The variety lodged badly except with the October-planted crop. For experimental purposes, the plants were tied together to keep them standing. If the plants had completely lodged, the yields would have been far less than with the crops planted in March, May, and July. Peta yields well in the dry season but not in the others. Peta is non-seasonal in duration, but it produces different grain yields in different seasons.

The differences in the yield of BPI-76 among seasons were great. Its optimum duration for maximum yield is about 170 days. The variety will give a fairly good crop yield if planted at the Institute in late May, June, or July. The big fluctuation of yield is associated with its strong sensitivity to photoperiod. BPI-76 is seasonal in duration and produces different grain yields in different seasons.

Table 1.3. Grain Yield per Crop and per Day in the Main Field for Three Varieties in Four Seasons, IRRI, 1962-1963.

Date planted	Dry grain (ton/ha)			Dry grain in main field (kg/ha/day)		
	Tainan-3	Peta	BPI-76	Tainan-3	Peta	BPI-76
March 15	4.89	3.80	4.80	49.9	30.4	22.6
May 3	4.30	4.32	5.63	43.9	35.7	36.8
July 16	5.10	3.21	4.29	51.0	29.1	38.6
Oct. 26	5.69	6.04	2.88	50.8	53.9	29.7

Grain Production per Day of Growth

As growth duration differed markedly among varieties in the four seasons, the "productivity" of each crop can be expressed as grain produced per day in the main field (Table 1.3) rather than as the grain yield per crop.

Tainan-3 had small seasonal differences in grain productivity per day in the main field. The productivity per day of Peta was high in the dry season, but it was low in the other seasons. BPI-76 planted in May gave a high grain yield but its duration was long. The productivity per day of the crop planted in July was the largest. The differential optima for yield per crop and for yield per day complicates the choice of time of planting for the seasonal varieties.

Total Plant Weight and Panicle-straw Ratio

The total dry weight of the plant increased with time. The increase initially was rather slow, became active, and then gradually decreased at later stages of growth (Fig. 1.6).

At the early stages of growth, Peta grew more rapidly than the other varieties, but after flowering, the increase in dry weight was negligible to nil. Tainan-3 grew more slowly, but it continued to increase in weight to the end of growth.

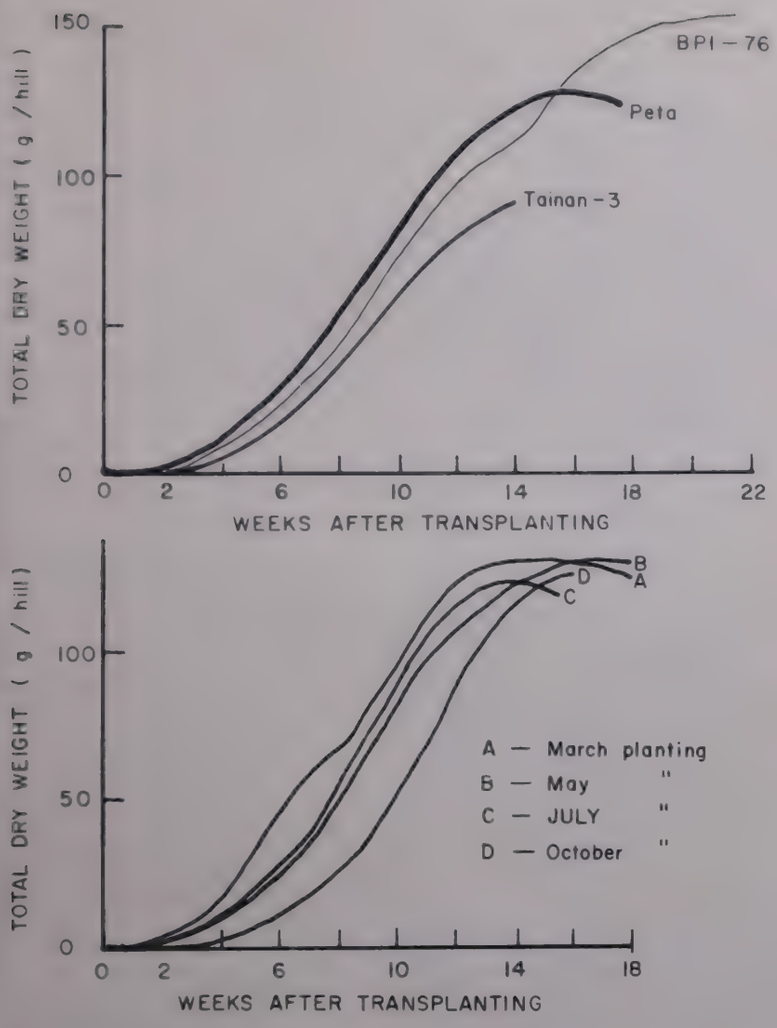


Figure 1.6. Total dry weight at successive stages of growth of three varieties planted at IRRI, May, 1962 (top), and of the variety Peta, when grown in four different seasons, IRRI, 1962-63 (bottom).

BPI-76 grew at a moderate rate and maintained this rate for a longer period. The period when the growth rate was relatively slow coincided with the vegetative-lag phase.

When Peta was planted in March, the growth rate at the early stages was rapid, but this decreased at the later stages; on the other hand, in the crop planted in October, it was slower at the early stages after which it maintained a rather high rate to the end of growth (Fig. 1.6).

Generally, under ordinary field conditions, a rapid growth rate at the early stages of growth is followed by a relatively slow growth rate.

The ratio of the panicle weight to the straw weight at harvest (Table 1.4) was large in Tainan-3 and small in Peta. It was small in the crop planted in March and large in the dry season crop planted in October.

The grain yield is approximately the product of the total dry weight and the panicle-straw ratio. As the grain is the objective of rice cultivation, both factors must be considered.

Peta grew rapidly and attained a high total weight, but the panicle-straw ratio was small; hence, the grain yield was small. But in the October planting, the ratio was large and the grain yield was high.

Tainan-3, a slow-growing variety with small total weight but large panicle-straw ratio, produced a high grain yield. The planting season greatly affected the growth of BPI-76, a photosensitive variety. In the rainy season, the total dry weight was so high that, despite the small panicle-straw ratio, the yield was high. When planted in October, BPI-76 had a small total weight; the grain yield was low in spite of the large panicle-straw ratio.

These data indicate that a high grain yield is obtained when the total weight of the plant and the panicle-straw ratio balance.

Dead Leaves

The ratio of the weight of dead leaves to the straw weight of Tainan-3 was smaller than for the other varieties (Table 1.4). The ratio was great in the May planting and small in the October planting.

Generally, if vigorous growth at the early stages results in crowding and mutual shading, the lower leaves die. Shading and death of leaves are not serious in the short duration varieties as these do

Table 1.4. Total Dry Weight at Harvest, Panicle-straw Ratio, and Percentage of Dead Leaves for Three varieties Grown in Four Seasons, IRRI, 1962-1963.

Date planted	Tainan-3	Peta	BPI-76
Total dry weight at harvest (g/hill)			
March 15	107	143	209
May 3	93	121	157
July 16	94	117	119
Oct. 26	95	128	59
Panicle-straw ratio			
March 15	0.91	0.43	0.37
May 3	0.81	0.57	0.58
July 16	1.10	0.38	0.68
Oct. 26	1.23	0.89	1.41
Weight dead leaves/total straw weight, at harvest (%)			
March 15	18	32	33
May 3	4	49	50
July 16	15	37	32
Oct. 26	19	28	26

not produce excessive vegetative growth under normal field conditions.

Morphological Characteristics

Height

Peta was much taller than Tainan-3 in the rainy season; in the dry season, however, it was only slightly taller (Table 1.5).

Season did not affeot the height of Tainan-3. Although season affected the growth duration of Peta only slightly, it affected the height greatly. BPI-76 planted in the dry season was extremely short, but it was tall in the crops planted in March and May.

Tiller Number and Effective Tiller Percentage

At the early growth stages, Peta tillered far more actively than the other varieties. After reaching the maximum tiller number stage, however, its tillers decreased significantly (Fig. 1.7). Tainan-3 and BPI-76 tillered slowly in the early stages, but later showed small decrease in tiller number.

All varieties tillered actively at the early stages of growth in the crops planted in March, May, and July, and less actively in the crop seeded in October. The decrease in tiller number after the maximum tiller number stage was extremely significant in the earlier three plantings, but it was relatively small in the dry season crop. Final tiller numbers were about equal in all seasons (Table 1.5).

The effective tiller percentage of Tainan-3 was far greater than any of the other varieties; that of Peta was small (Table 1.5).

At the spacing and nitrogen level employed, active tillering of Peta at the early stages of growth was followed by a remarkable decrease in tiller number after the maximum tiller number stage; this resulted in a low percentage of effective tillers. It also should be noted that the smaller decrease in the tiller number after the maximum tiller number stage was associated with the shortness of the plant height.

Table 1.5. Height at Harvest, Maximum Tiller Number, and Percentage of Effective Tillers of Three Varieties Grown in Four Seasons, IRRI, 1962-1963.

Date planted	Tainan-3	Peta	BPI-76
Height at harvest (cm)			
March 15	133	190	174
May 3	145	198	178
July 16	135	192	154
Oct. 26	126	134	114
Maximum tiller number per hill			
March 15	24.0	36.9	28.0
May 3	20.7	34.9	21.3
July 16	21.6	32.8	19.5
Oct. 26	15.7	21.8	13.5
Effective tiller percentage			
March 15	83	44	52
May 3	71	38	54
July 16	89	45	79
Oct. 26	80	71	72

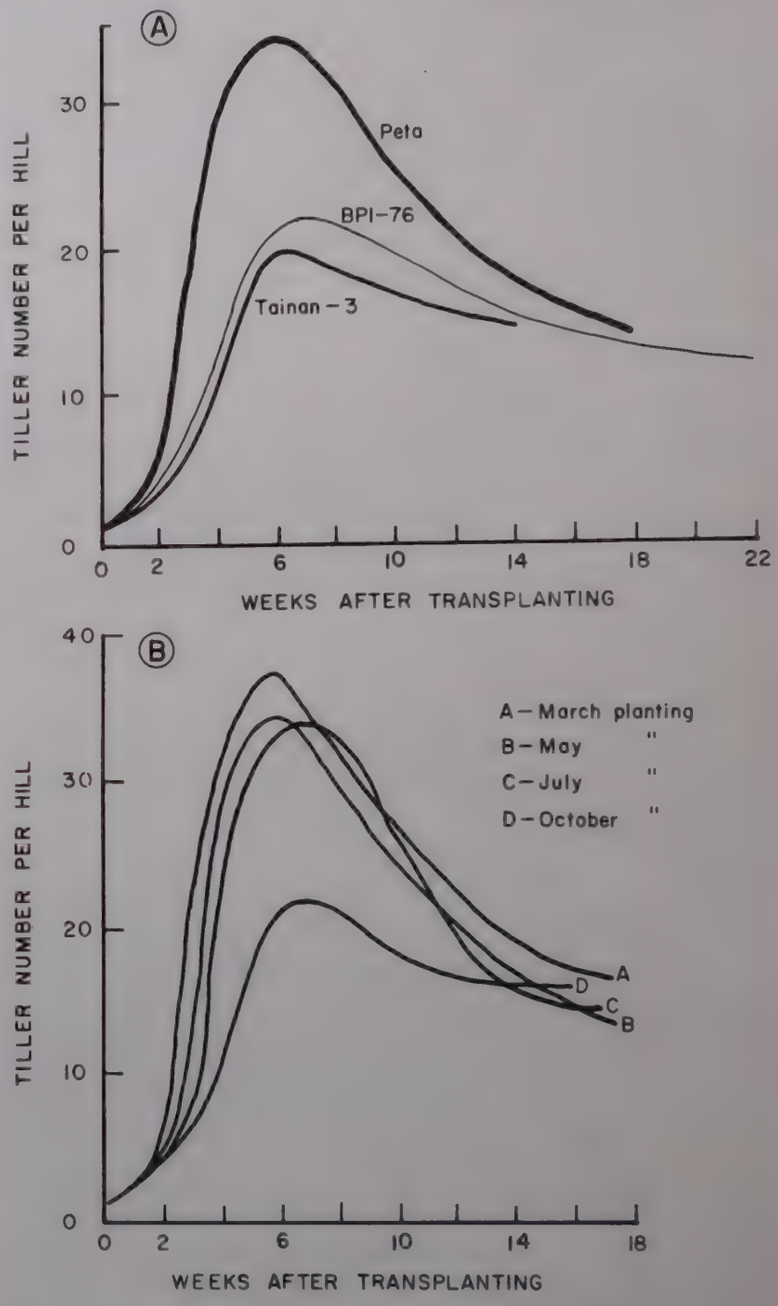


Figure 1.7. Tiller number at successive growth stages of three varieties planted at IRRI, May (A), and of Peta during four different seasons, IRRI, 1962-63 (B).

Characters of Leaves on Main Culm

At the lower positions on the culm, the leaves are short; but they become longer at upper positions to a point, after which they again become shorter (Fig. 1.8).

In different seasons, varieties vary in the number of leaves on the main culm and in the length as well as in the position of the longest leaf (Table 1.6).

Average leafing interval was 5 or 6 days (Table 1.6). At the early stages of growth, it was less than 5 days but it increased at later stages. Because of the relatively constant leafing interval, the number of leaves on the main culm is closely related to growth duration.

Tainan-3 had 15 leaves on the main culm in each season, and the season had little effect on leaf length. The longest leaf, about 60 cm, was the 13/0 or 14/0. The fact that the longest leaf was the second or third leaf from the flag-leaf indicates that the nutritional status of the plant was good to the end of growth.

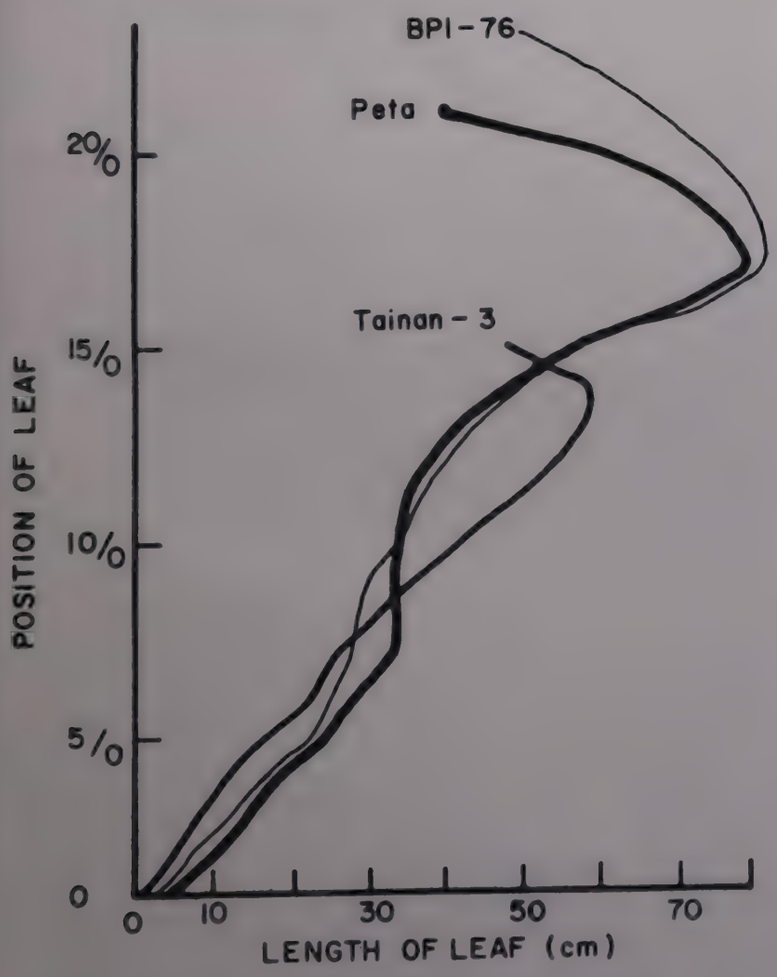


Figure 1.8. Length of leaves at various positions on the main culm for three varieties planted at IRRI, May 3, 1962.

Table 1.6. Length and Position of Flag-leaf and Longest Leaf on Main Culm, and Average Leafing Interval for Three Varieties Grown in Four Seasons, IRRI, 1962-1963.

Date planted	Tainan-3	Peta	BPI-76
Length (cm) and position of flag-leaf			
March 15	50 (15/0)	45 (21/0)	50 (23/0)
May 3	48 (15/0)	40 (21/0)	50 (23/0)
July 16	45 (15/0)	30 (18/0)	50 (18/0)
Oct. 26	25 (15/0)	22 (16/0)	33 (13/0)
Length and position of longest leaf			
March 15	58 (14/0)	77 (17/0)	73 (16/0)
May 3	60 (14/0)	80 (17/0)	83 (17/0)
July 16	57 (14/0)	81 (15/0)	71 (16/0)
Oct. 26	60 (13/0)	63 (13/0)	45 (11/0)
Number of green leaves at flowering			
March 15	4.5	3.5	3.5
May 3	5.5	2.5	3.5
July 16	6.5	3.5	3.5
Oct. 26	7.0	4.5	4.5
Average leafing interval (days)[a]			
March 15	5.6	5.4	7.7
May 3	5.6	5.3	6.3
July 16	5.6	5.6	6.0
Oct. 26	6.2	6.3	5.8

[a] Days from sowing to flowering/number of leaves on the main culm + 1.

In Peta, 21/0 was the flag-leaf in the crops planted in March and May, whereas in the crops seeded in July and October, the 18/0 and 16/0 were the flag-leaves, respectively. In the case of the March and May plantings, the longest leaf, about 80 cm, was 17/0. The longest leaf was the fifth from the flag-leaf, indicating that the plant suffered from malnutrition at the later stages of growth. The flag-leaf of Peta was shorter, but the longest leaf was much longer than that of the other varieties. In the October planting, the longest leaf, the 13/0, was 63 cm, indicating that the general condition of the leaves on the main culm of Peta in the October planting was similar to that of Tainan-3.

In BPI-76, the leaf number varied markedly with season. In the March planting, the flag-leaf was the 23/0 and in the October planting, it was the 13/0. The pattern of the leaf length at various positions in the March and May plantings was similar to that of Peta in the same seasons. In the

October planting, there were 13 leaves in the main culm and the longest leaf, the 11/0, was 45 cm.

As the plant grows, new leaves emerge one after another at the top of the culm, but old leaves at the lower positions die. As the number of active leaves at any given growth stage largely determines total photosynthetic activity, the balance between formation and death of the leaves is important.

At the flowering stage in the May planting, Tainan-3 had five green leaves, whereas Peta and BPI-76 had three (Fig. 1.9).

The number of green leaves at flowering in the March and May planting was less than in the October planting. This was the case with all varieties.

Tainan-3 had fewer leaves on the main culm than Peta or BPI-76, but more were alive.

This test indicated that both the number of leaves on the main culm and the number of dead leaves increased with duration of growth. A more satisfactory balance occurred when the growth duration was relatively short.

Tainan-3 had many green leaves when it flowered. The longest leaf was the second from the flag-leaf and it was active; this indicates that the photosynthetic activity of the plants at flowering was high. The dead leaves at the lower positions were fewer and smaller; hence, the amount of dead leaves was small. Peta and BPI-76 in the March and May plantings had few green leaves and the sizes of these green leaves were small; consequently, the photosynthetic activity of the plants at flowering could not be great. The longest leaves were the fifth or sixth from the flag-leaf, and these were dead at flowering. As there were many large dead leaves, the weight of dead leaves was great.

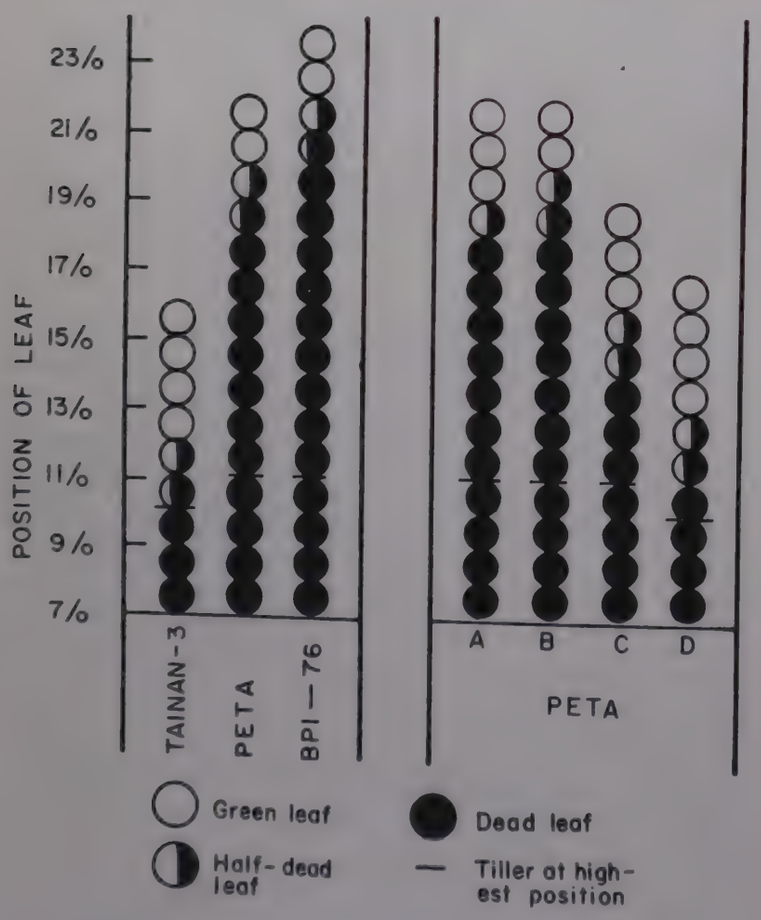


Figure 1.9. Condition of leaves on the main culm at flowering of three varieties planted May 1, 1962 (left), and that of Peta leaves when the crop was planted March (A), May (B), July (C), and October (D), IRRI, 1962-63 (right).

Internode Elongation

The sequence of internode elongation and length of individual internodes of Peta in the May planting are shown in Fig. 1.10.

There was no measurable internode elongation until about the maximum tiller number stage. The

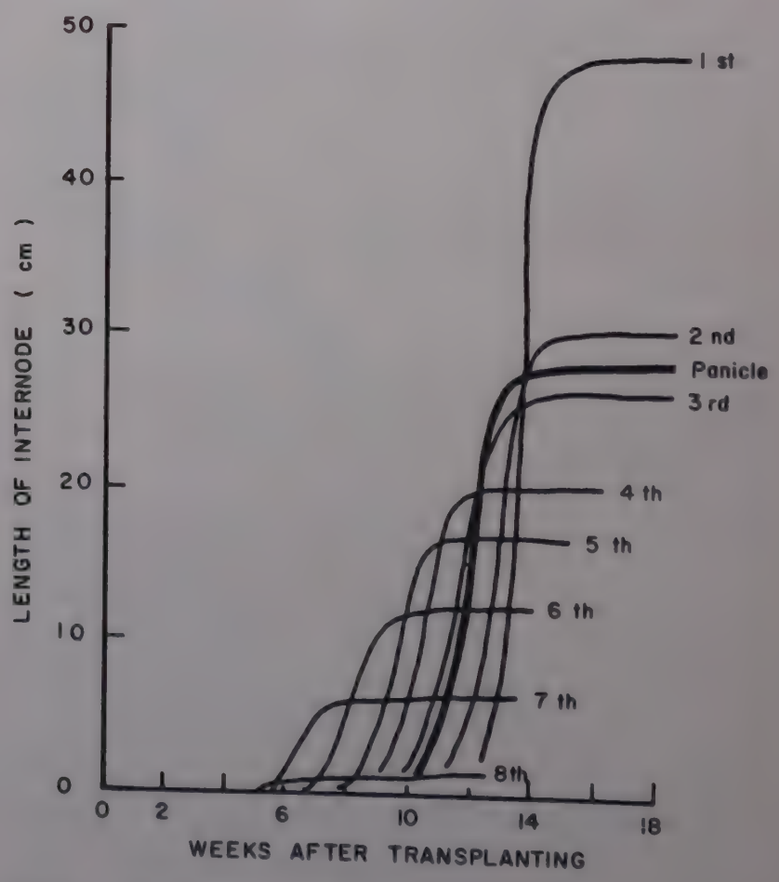


Figure 1.10 Elongation of each internode of Peta planted in July. The first internode is between the panicle and 21/0 (the flagleaf); the second internode is that between 21/0-20/0, etc.

lower internode elongated first, followed in order by the upper ones. At the ear-initiation stage, the fourth internode from the top was elongating. The third internode elongated almost simultaneously with the development of ear-primordium, and the second and first internodes elongated after the development of ear-primordium.

Three internodes elongated after the ear-initiation stage, excluding the internode which had already started to elongate. The interval between one internode elongation and the next was about the same as the interval between the formation of successive leaves. The number of internodes elongating before ear-initiation seemed to be a function of the duration of the vegetative-lag phase.

At the ear-initiation stage, the elongated internodes of Tainan-3 were few in number and short in total length (Table 1.7, Fig. 1.11). Peta had long elongated internodes, with many elongated internodes in the May planting, but few in the October planting. At flowering, the same tendency was noted, and a close correlation appeared between the total length of elongated internodes at the ear-initiation stage and at the flowering stage.

Lodging

Tainan-3 did not lodge in any season; Peta was inclined to lodge heavily before flowering, except in the October planting. In the May planting, BPI-76 lodged slightly after flowering.

The lodging of Peta can be related to the tall and soft culm characteristic of the variety. In the October planting, Peta was short and did not lodge. In the other plantings, the lodging of Peta may have been related to the marked elongation of the lower internodes before the ear-initiation stage.

Characters other than height no doubt also are related to lodging. Tainan-3 has a thin, flexible culm. The culm of Peta is thick but weak, and lodging generally occurs at the base of the culm. The development of the roots also may be related to lodging. BPI-76 has a thick culm and resists lodging; however, it lodges under some conditions associated with breakage of the culm.

Table 1.7. Total Length and Number of Elongated Internodes at Ear-initiation and at Flowering for Three Varieties Planted in Four Seasons, IRRI, 1962-1963.

Date planted	Tainan-3		Peta		BPI-76	
	Length (cm)	No.	Length (cm)	No.	Length (cm)	No.
At ear-initiation						
March 15	8	2	52	5	45	6
May 3	8	2	53	5	57	6
July 16	7	2	25	4	9	3
Oct. 26	7	2	7	3	0	0
At flowering						
March 15	89	5	159	8	140	9
May 3	92	5	163	8	145	9
July 16	90	5	145	7	105	6
Oct. 26	87	5	111	6	72	4

Figure 1.11 Condition at the ear-initiation stage of the main culm of Tainan-3 (right) and Peta (left) in the May planting.

Light Transmission Ratio

The light transmission ratio decreased with growth (Fig. 1.12). This resulted from the increase in the leaf area of the plants.

The light transmission with Peta decreased more rapidly than with other varieties. A high level was maintained for a longer period with Tainan-3. With Peta, the decrease in light transmission ratio with growth occurred early in the March planting and later in subsequent plantings. The decreases in ratio (Table 1.8) appear closely associated with increases in tiller number (Fig. 1.7).

The light transmission ratio at the maximum tiller number stage, as well as at the flowering

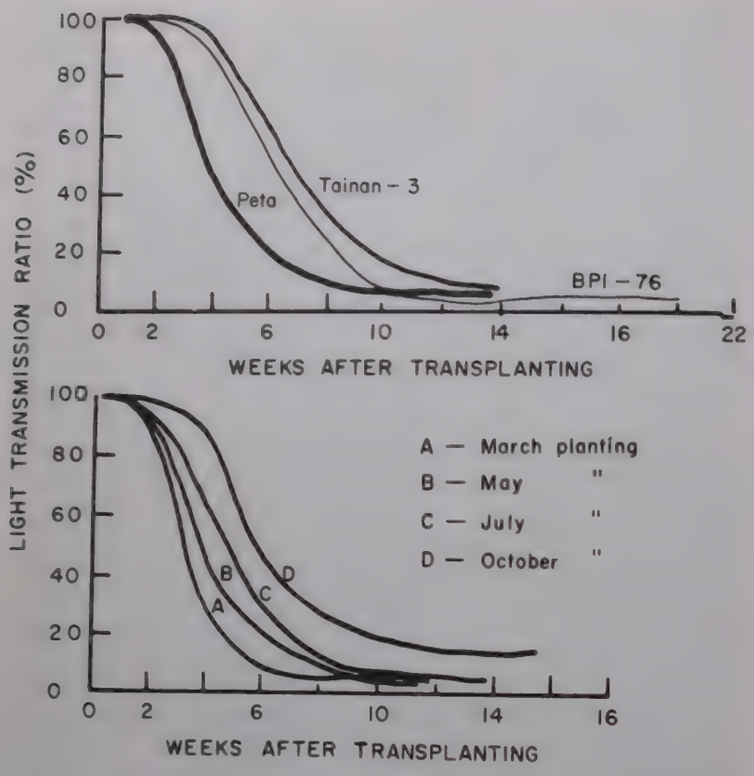


Figure 1.12. Light transmission ratio in field plots of three varieties planted at IRRI, May 3, 1963 (top), and in field plots of the variety Peta planted at the four dates indicated (bottom).

stage, was highest with Tainan-3 and lowest with Peta. It was low in the March planting and increased in subsequent plantings.

These data indicate that under ordinary field conditions, active tillering and tall growth result in serious mutual shading.

Table 1.8. Light Transmission Ratio at Maximum Tiller Number and at Flowering Stages in Field Plots of Three Varieties in Four Seasons, IRRI, 1962-1963.

Date planted	Tainan-3	Peta	BPI-76
At maximum tiller number stage			
March 15	23	6	16
May 3	60	21	56
July 16	60	31	56
Oct. 26	61	38	72
At flowering			
March 15	15	4	2
May 3	20	2	2
July 16	22	8	6
Oct. 26	25	11	56

Nitrogen and Carbohydrates

Nitrogen and Carbohydrate Relationship

Nitrogen and carbohydrates (the total of the nonreducing and reducing sugars and starch) are the major constituents involved in the metabolism of the plant.

The percentages of nitrogen and carbohydrate in the straw and also the amount of these in the straw and in the panicle, at successive stages of growth, are given in Figure 1.13 for the May planting of Peta.

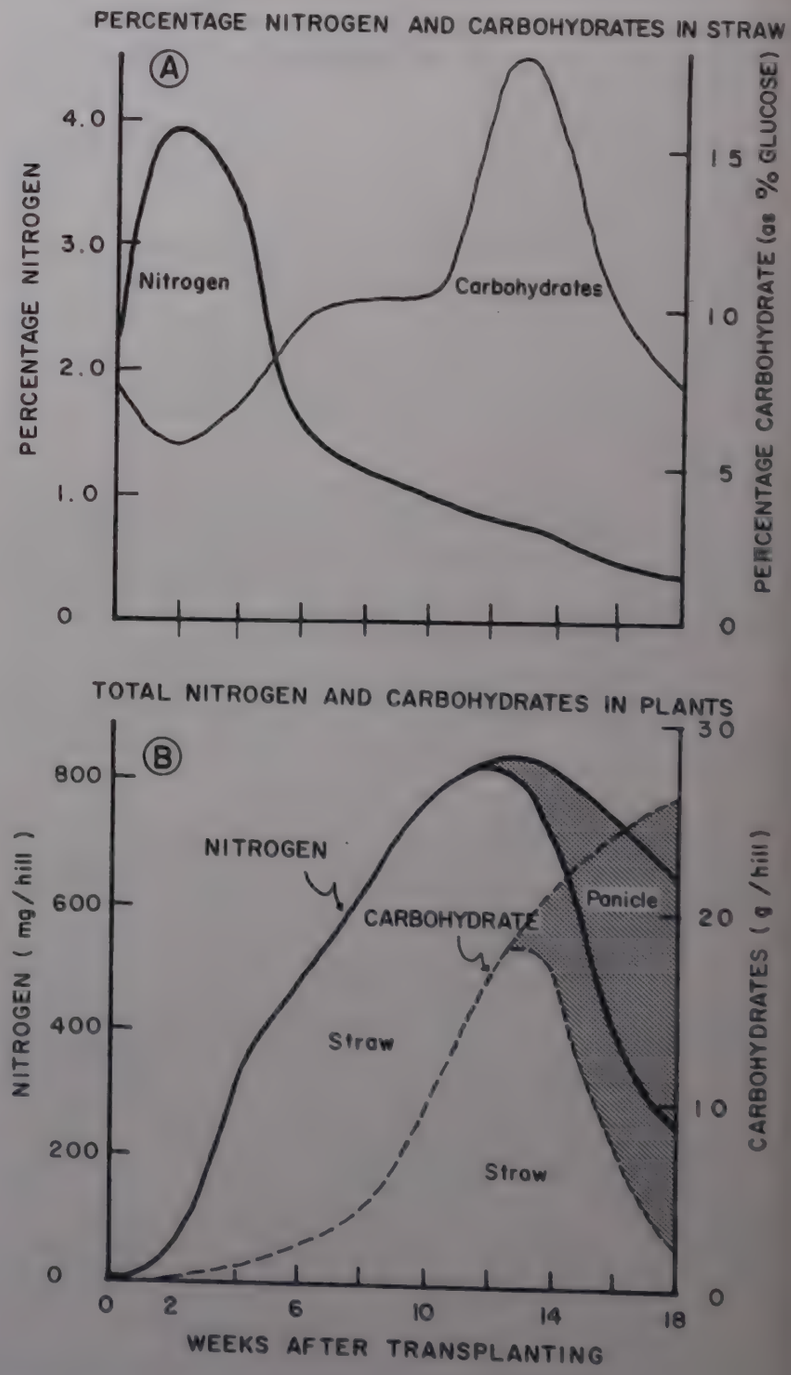


Figure 1.13. Percentage (A) and total amount (B) of nitrogen and carbohydrates in Peta when planted at IRRI, May 3, 1963.

The percentage of nitrogen in the plant increased for about 2 weeks after transplanting, while the carbohydrate content decreased slightly. Then, the percentage of nitrogen decreased rapidly for about a month, after which it decreased slowly. The carbohydrate content increased as the nitrogen content started to rapidly decrease; this indicates that nitrogen and carbohydrates counteracted each other. The percentage of carbohydrates remained about constant during the vegetative-lag phase, but rapidly increased in the following reproductive phase. After flowering, the percentage of carbohydrate in the straw decreased sharply. The percentage of nitrogen in Tainan-3 decreased somewhat more rapidly after flowering than at the reproductive phase.

The total nitrogen in Peta increased as the plant grew. At the early stages of growth, the rate of nitrogen uptake was far greater than the rate of carbohydrate accumulation. The amount of nitrogen in the plants reached a maximum about 2 weeks before flowering and then there was a significant loss of nitrogen from the plants. Much of the nitrogen was translocated from the straw to the panicle during the ripening phase.

Total carbohydrates increased slowly during the early stages of growth, and more actively during the reproductive phase. The carbohydrates in the straw disappeared quickly after flowering, indicating that a major part of the carbohydrates stored in the straw was translocated to the grain. The total carbohydrates in the plants increased to the end of growth. The increase after flowering was small in comparison to the amount translocated from the straw to the grain, indicating that much of the starch in the grain previously was stored in the straw.

Percentage of Nitrogen in the Straw

At the early stages of growth, the percentage of nitrogen in Peta was higher than in the other two varieties, but at later stages of growth it was similar to or even lower than in the other varieties (Table 1.9).

The increases just after transplanting and the decrease after reaching the highest percentages of nitrogen were more marked in the March and May plantings, but these were more gradual in the crop planted in October.

At the maximum tiller number stage, the percentage of nitrogen in the straw varied from 2.0 to 1.5 percent. The data indicate that tillering stopped when the nitrogen content of the straw dropped below 1.7 percent. The percentage of nitrogen in the straw at the ear-initiation stage was high in Tainan-3 and low in Peta; it was low in the March and May plantings, but high in the October planting. The wide range of nitrogen percentage at the ear-initiation stage indicates that ear-initiation is not regulated or affected by nitrogen levels in the plant.

Table 1.9. Percentage of Nitrogen in Active Straw at Various Stages of Growth for Three Varieties Grown in Four Seasons, IRRI, 1962-1963.

Date planted	Tainan-3	Peta	BPI-76
At maximum tiller number stage			
March 15	1.54	1.95	1.64
May 3	1.50	1.54	1.65
July 16	1.81	1.96	1.75
Oct. 26	1.20	1.93	1.71
At ear-initiation			
March 15	1.54	0.94	0.50
May 3	1.50	0.93	1.00
July 16	2.32	1.50	1.75
Oct. 26	2.30	1.50	2.90
At flowering			
March 15	1.01	0.62	0.42
May 3	0.85	0.60	0.80
July 16	1.67	0.99	1.00
Oct. 26	1.00	0.83	1.20
At harvest			
March 15	0.52	0.34	0.36
May 3	0.63	0.34	0.43
July 16	0.67	0.46	0.67
Oct. 26	0.49	0.42	0.50

The variation at flowering among varieties and seasons in the percentage of nitrogen was similar to that at the ear-initiation stage.

In this test, regardless of variety or season, high nitrogen levels maintained during a long vegetative phase usually resulted in low nitrogen levels in the straw during the reproductive phase.

At the early stages of growth, nitrogen uptake by Tainan-3 was considerably slower than uptake by Peta (Fig. 1.14). Nitrogen uptake by Tainan-3 continued to the end of growth; that of Peta reached a peak well before harvest, then substantial losses of nitrogen occurred (Table 1.10). In the case of BPI-76, nitrogen uptake apparently slowed during the vegetative-lag period, became active again after ear-initiation, reached a maximum, and then decreased.

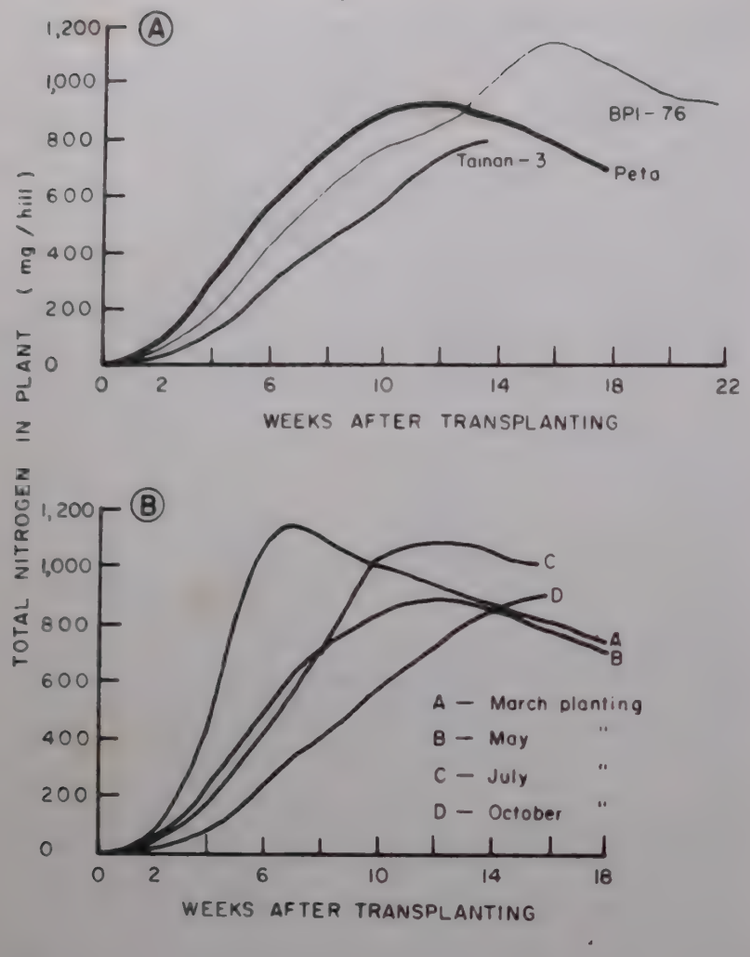


Figure 1.14. Total nitrogen in the plant at successive stages of growth for three varieties planted in May (A) and total nitrogen in Peta plants grown in four different seasons, IRRI, 1962-63 (B).

The nitrogen uptake by Peta in the early stages of growth was active in the March planting and slower in the October planting. The loss of nitrogen from the plants was great in the March planting and negligible in the October planting.

Generally speaking, active nitrogen uptake at the early stages of growth was followed by a loss of nitrogen at later stages.

At harvest, 40-60 percent of the maximum amount of nitrogen absorbed by the plants was in the panicle; the rest was leached from the plant or remained in the straw (Table 1.10). The percentage of nitrogen in the panicles of Peta was smaller than that of the other two varieties and considering all varieties, the percentage of nitrogen in the panicles was lower in the March and May plantings than in the other season.

The nitrogen in the panicle can be classified into two categories: nitrogen absorbed after flowering, and nitrogen absorbed before flowering and translocated from the straw to the panicle after flowering (Table 1.10). With Peta, no nitrogen was absorbed after flowering; thus, all the nitrogen in the panicle was translocated from the straw. With Tainan-3, about half of the nitrogen in the panicle was derived from the nitrogen absorbed after flowering. With BPI-76 in the March and May plantings, no nitrogen was absorbed after flowering, but in the July and October plantings, a significant proportion of nitrogen was absorbed after flowering.

Table 1.10. Percentage of Nitrogen Lost from the Plants, Absorbed after Flowering, and Translocated from Straw to Panicle in Three Varieties Grown in Four Seasons, IRRI, 1962-1963.

Date planted	Tainan-3	Peta	BPI-76
Percentage of nitrogen lost from the plants			
March 15	0	25	25
May 3	0	23	19
July 16	0	21	0
Oct. 26	0	4	0
Percentage of nitrogen in the panicle at harvest[a]			
March 15	54	38	40
May 3	57	34	51
July 16	59	38	57
Oct. 26	59	59	70
Percentage of nitrogen absorbed after flowering			
March 15	40	0	0
May 3	68	0	0
July 16	41	0	31
Oct. 26	40	0	58

[a] Nitrogen in the panicle at harvest/maximum amount of nitrogen absorbed by the plant.

Percentage of Carbohydrates in the Plant

At the early stages of growth in the May planting, Tainan-3 had a higher carbohydrate content than Peta (Fig. 1.15). This indicates that even though the nitrogen supplied to the plants was high, Tainan-3 stored some of the assimilation products as carbohydrates instead of using these to expand plant size. At this stage, the carbohydrate content of Peta was low, indicating that most of the assimilation products were being used to absorb nitrogen and to expand the plant.

With Tainan-3, the percentage of carbohydrate in the straw at the flowering stage was lower than that of the other two varieties. In addition, the straw weight of Tainan-3 was light, demonstrating that ripening depended to a great extent on the products assimilated after flowering. On the other hand, with Peta and BPI-76, the carbohydrate

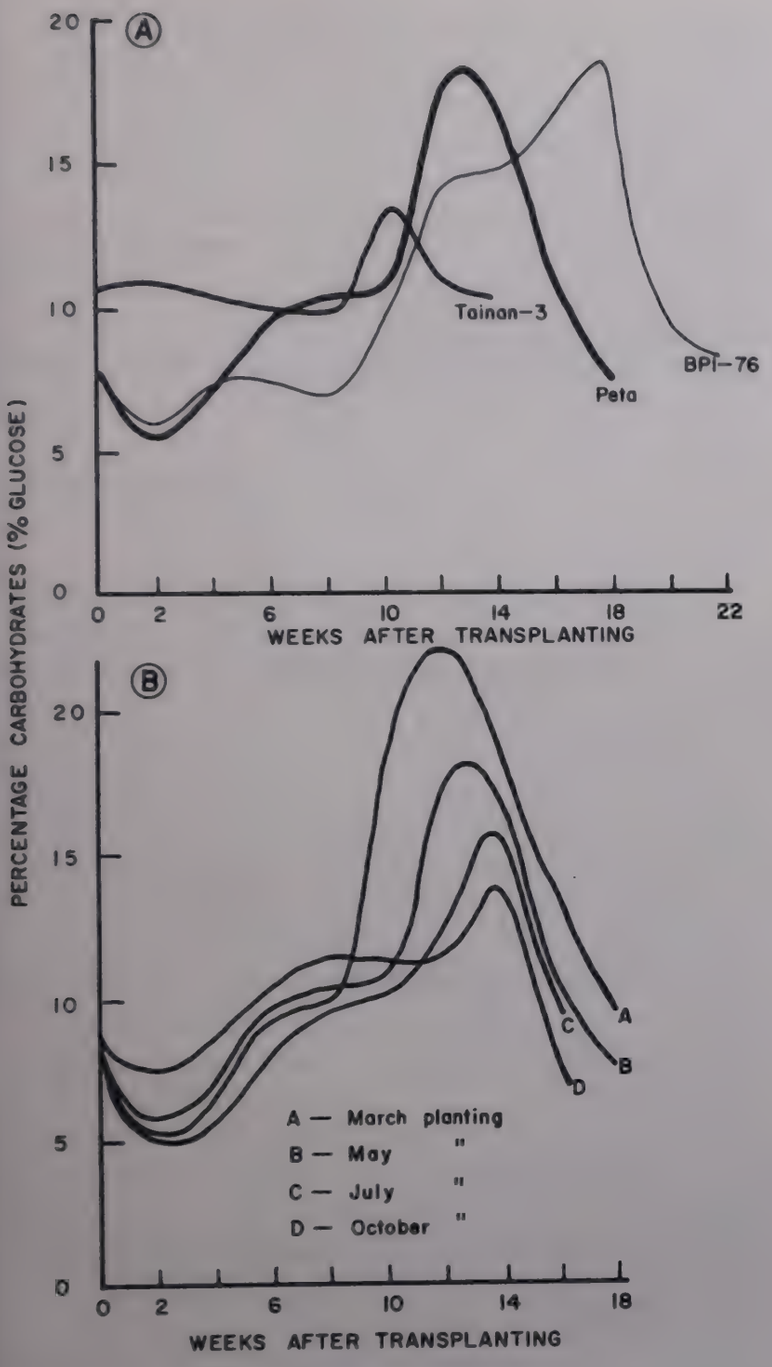


Figure 1.15. Percentage carbohydrates in the straw of three varieties planted in May (A) and in the straw of Peta planted at the four dates indicated (B).

content at flowering was high and the straw weight was heavy, indicating that much of the starch accumulated in the grain during ripening came from carbohydrates stored in the straw before flowering.

In the case of Peta, the carbohydrate content at the early stages of growth was higher in the October planting than in the other three. At the flowering stage, the percentage was far less in the October than in the March planting. In the October planting, the fluctuation in the carbohydrate content of Peta during growth was similar to that of Tainan-3 planted at any of the four dates.

Nitrogen Content of Leaves, Main Culm

There were large differences in the percentages of nitrogen among leaves on the main culm (Fig. 1.16). The nitrogen levels of the upper leaves generally were higher than those of the lower ones. At the early stages of growth, the difference in the nitrogen level among leaves at different positions was larger, but became smaller with the age of the plant. No differences in nitrogen level of specific leaves appeared associated with varieties or season.

The percentage of nitrogen in the active center leaf (the third leaf from the top-growing leaf) (Tanaka, 1961) was similar to that of the whole straw at each growth stage, except in the later stages when it was slightly greater than that of the whole straw. This may be caused by the increased proportion of culm to leaves resulting from internode elongation at later stages of growth. However, the correlation (Fig. 1.17) indicates that analysis of the active center leaf may provide a convenient measure of the status of the whole plant.

An iodine test of each leaf indicated that there was a gradual change in starch accumulation among leaves at different positions. The top-growing leaf had some starch at its growing point. The next to the top leaf gave almost no starch reaction. There was a great accumulation of starch in the sheath of the active center leaf, and there

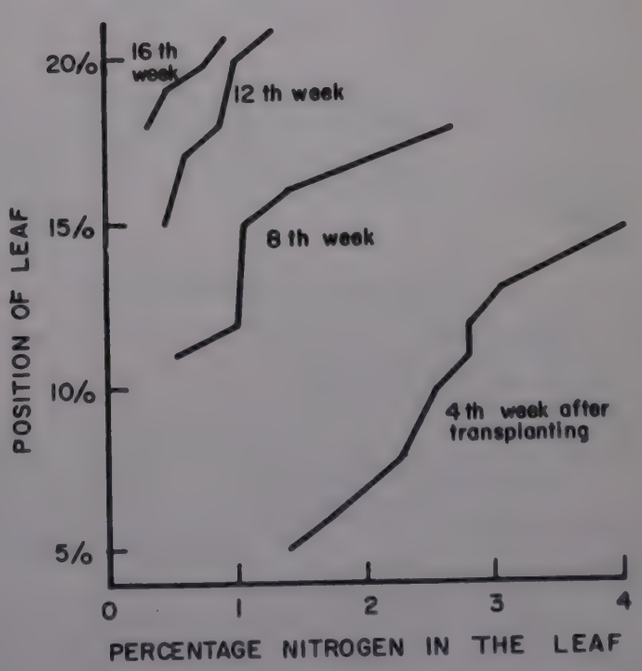


Figure 1.16. Percentage nitrogen in various leaves at different stages of growth when Peta was planted in May.

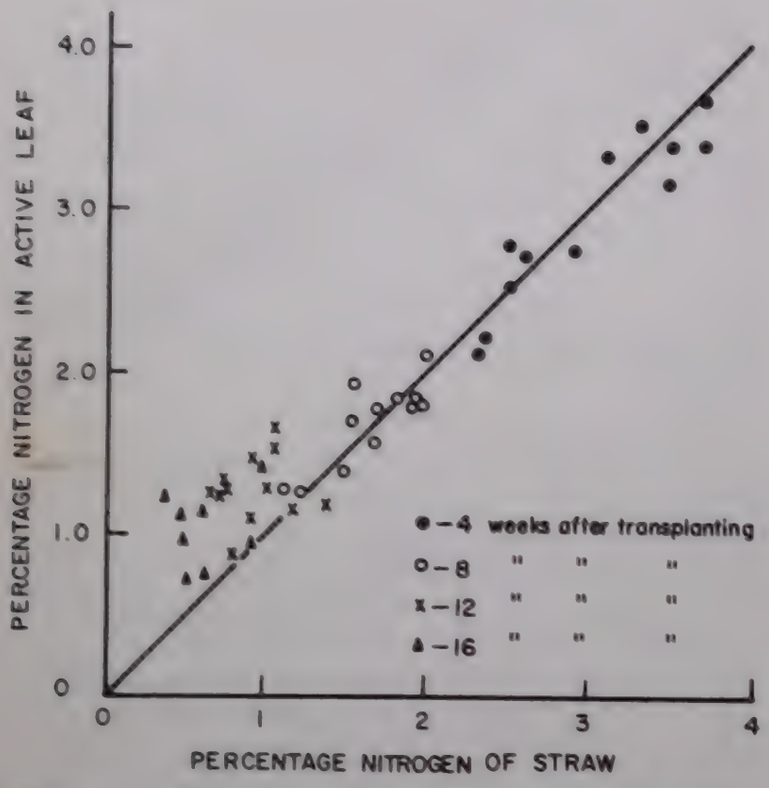


Figure 1.17. Relation between percentage nitrogen in straw and in active center leaf of three varieties planted in four different seasons.

was decreasing accumulation of starch from the active center leaf to the lower leaves.

In the May planting, Tainan-3 gave a stronger starch reaction than Peta at the early stages of growth, but this starch reaction was weaker than that of Peta at later stages of growth. The differences in Peta among seasons followed the pattern of the percentage of carbohydrates in the different seasons.

The iodine test may be used to provide semiquantitative information on the carbohydrate accumulation in the plants, as has been reported (Arashi and Eguchi, 1955).

Mineral Elements

Mineral Element Content at Successive Growth Stages

The levels of several minerals in the active straw, dead leaves, and panicles of Peta at various stages of growth in the May planting are reported as percentages of the dry weight of the plant parts involved (Fig. 1.18).

In the active straw, phosphorous levels decreased for a time after transplanting, then increased, and after reaching a peak, decreased toward the end of growth. Potassium content increased after transplanting, reached a maximum, then decreased; there was a slight increase after flowering. Calcium content increased for about 2 weeks after transplanting, decreased slightly, then maintained a relatively constant value to the end of growth. Magnesium content increased after transplanting, decreased before ear-initiation, reached a peak at flowering, and then decreased. Iron content reached its maximum 2 weeks after transplanting, decreased, and then increased once more after flowering. Manganese content increased slightly after transplanting, decreased until ear-initiation, increased again after ear-initiation, and then maintained a constant value. Silicon content decreased for 4 weeks after transplanting, then increased continuously until the end of growth.

Generally speaking, nutrient uptake is controlled by three factors: Nutrient level in the soil, nutrient absorbing power, and rate of weight increase of the plants. At the early stages of growth, the level in the soil and the absorbing power of the plants are high so that the levels of all elements in the plant are high. However, at later growth stages, root activity decreases so that the levels of metabolically absorbed elements also decrease. A low level in the plant also is related to a low level of these elements in the soil. The content of elements such as silicon, which are not metabolically absorbed and which maintain a high level in the soil, remains high.

Phosphorus and potassium contents in the dead leaves were far lower than those in the active straw, and, with growth, there was a decrease in content in the active straw. The data indicate that these elements translocate from old leaves to new ones. Calcium, magnesium, and manganese levels in dead leaves apparently were higher than those of the active straw, indicating a low mobility of these elements. But, there also was a gradual decrease with growth in the dead leaves, indicating some leaching of these elements from the dead leaves. Iron and silicon levels in dead leaves were much higher than those in the active straw, and there was a marked increase with growth. These elements do not translocate easily and do not leach out.

Process of Element Uptake

The amounts of mineral elements at successive growth stages in Peta planted in May are shown in Figure 1.19.

The uptake at early stages of growth was slow, but increased rapidly after a few weeks. The amount of some elements reached a maximum at

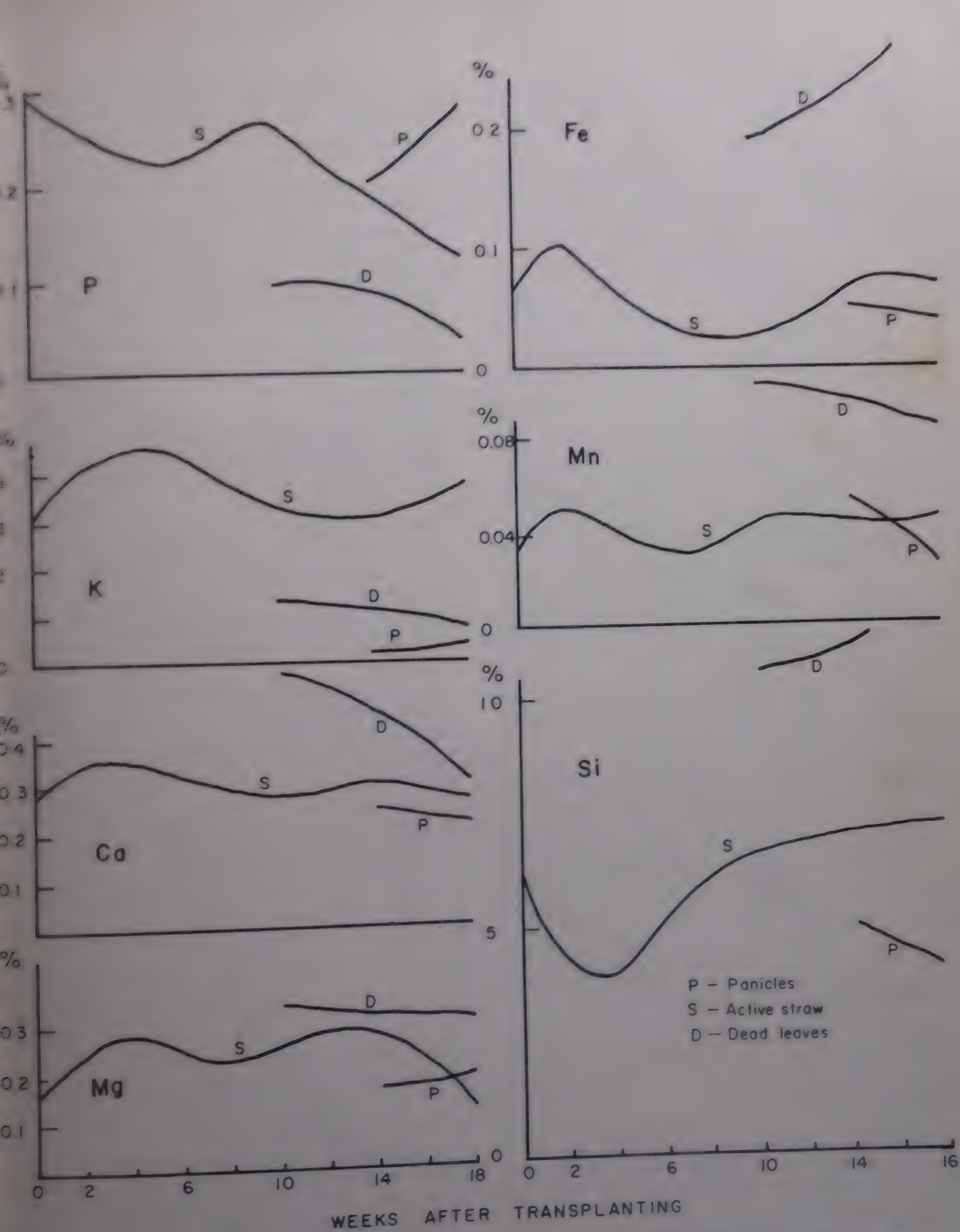


Figure 1.18. Mineral element levels in percentage of dry weight at successive stages of growth of Peta planted in May.

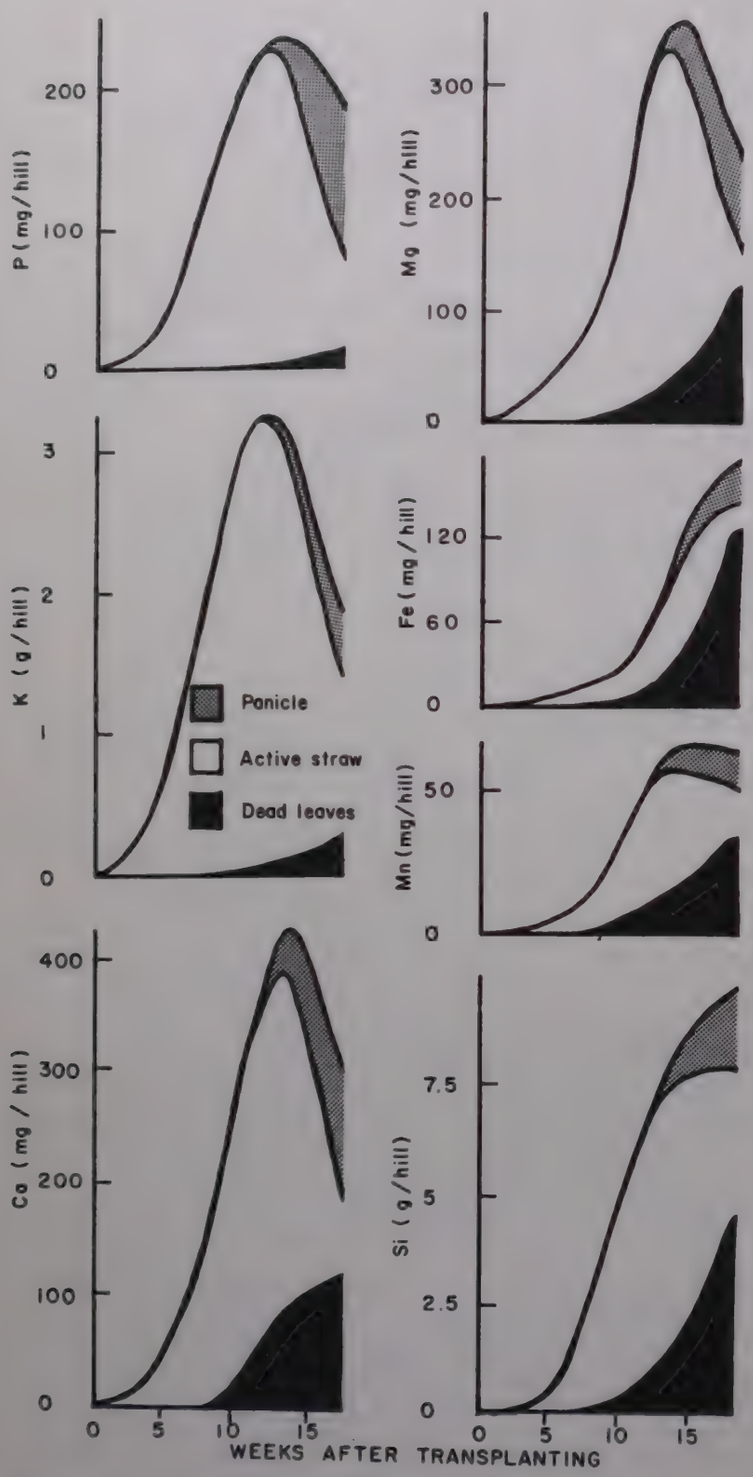


Figure 1.19. Amounts of elements in Peta planted May 3, 1963 in successive stages of growth.

the booting or flowering stage and then decreased; those of other elements continued to increase to the end of growth.

With the death of the lower leaves, some elements (i.e., nitrogen, phosphorus, potassium) disappeared from these, and only small amounts were left. Other elements remained in the dead leaves in large amounts.

During ripening some elements (i.e., nitrogen, phosphorus) translocated from the straw to the grain in large amounts, while others did not.

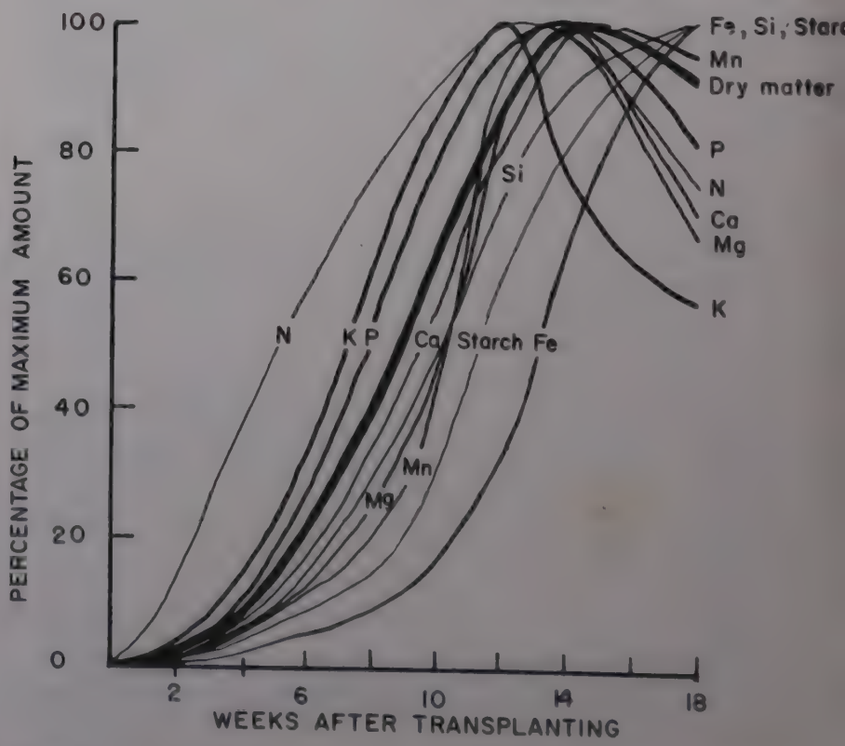
To compare the processes of absorption and loss more definitely, the amounts of elements in the plants at successive stages of growth are expressed as the percentage of the maximum amounts in the plants (Fig. 1.20).

The order in which active uptake took place was N, K, P, Ca, Mg, Mn, Si, and Fe. At early stages of growth, nitrogen, potassium and phosphorus uptake was more rapid than for other elements. Calcium, magnesium, and manganese absorption almost paralleled dry matter production. Silicon and iron accumulated in the plant after the plant was formed.

After reaching a maximum amount, there was a considerable loss of elements with the relative losses being in the order of K > Mg > Ca > N > P > Mn, Fe, Si. The loss of potassium was about 40 percent; that of nitrogen, calcium and magnesium, about 30 percent; and that of phosphorus, 20 percent. No iron, manganese, and silicon was lost.

The distribution of elements at harvest in the panicle, active straw, and dead leaves is shown in Fig. 1.21. The sequence of the distribution of elements in the panicle was P > N > Ca > Mg > Si, Mn > Fe > K.

More than 60 percent of the nitrogen and phosphorus in the plants at harvest was in the panicle, whereas 10 percent of potassium was there. Al-



Figures 1.20. Percentages of maximum amounts of elements and other substances occurring at various stages of growth in Peta planted at IRRI, May, 1963.

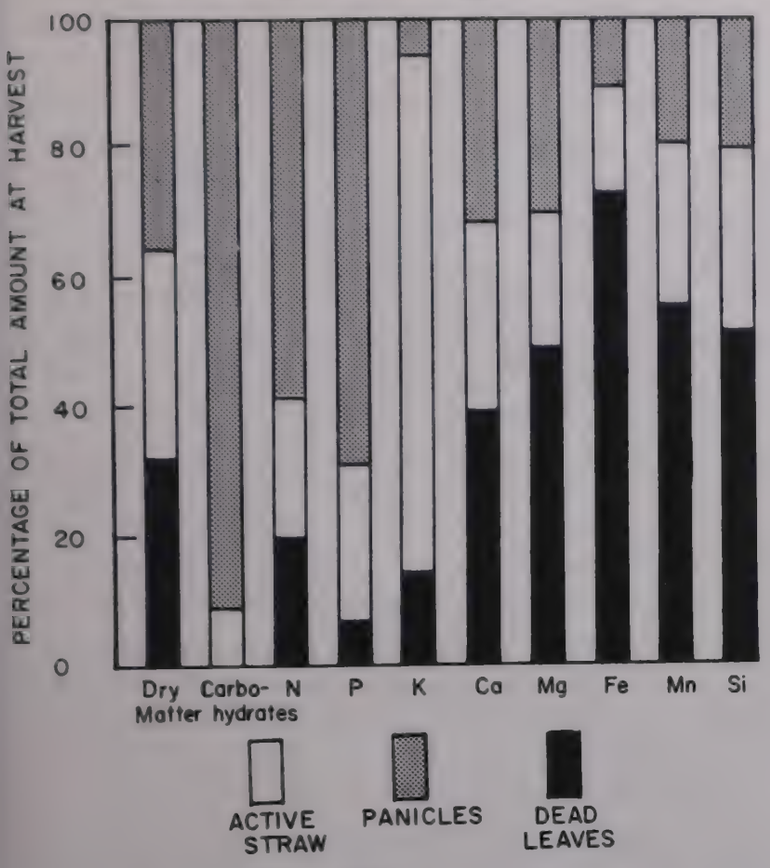


Figure 1.21. Distribution at harvest of elements and other substances in various parts of Peta plants when planted in May, 1963.

though the proportion of iron, manganese, and silicon in the panicle was 10-20 percent, these do not seem to have been translocated from the straw to the panicle, but to have been absorbed after flowering.

The proportions of the elements in the dead leaves were of the following order: Fe, Mn, Si, Mg, Ca > N > K > P. Iron, manganese, and silicon remained in the dead leaves without translocating. Nitrogen, phosphorus, and potassium readily moved out of the dead leaves.

Varietal and Seasonal Differences in Element Content

Because of the complicated fluctuations in mineral element content with growth, it is difficult to compare varietal or seasonal differences. Some information can be obtained from the summary of the average content of elements, as given in Table 1.11.

Tainan-3 appeared low in potassium and higher in iron, manganese, and silicon. Peta was relatively high in potassium but low in manganese and silicon. There were no noticeable differences among varieties in phosphorus, calcium or magnesium content.

Table 1.11. Average Content of Mineral Elements in Active Straw of Three Varieties Grown in Four Seasons, IRRI, 1962-1963.

Elements	Element content as percentage of dry weight of straw						
	Varieties			Date planted			
	Tainan-3	Peta	BPI-76	Mar. 15	May 3	July 16	Oct. 26
N	1.77	1.66	1.60	1.86	1.37	1.71	1.76
P	0.21	0.23	0.21	0.22	0.21	0.23	0.21
K	3.18	3.48	3.28	3.13	3.53	3.66	2.95
Ca	0.26	0.29	0.29	0.32	0.29	0.28	0.23
Mg	0.24	0.22	0.24	0.21	0.25	0.23	0.24
Fe	0.112	0.097	0.092	0.085	0.062	0.116	0.097
Mn	0.044	0.031	0.028	0.029	0.036	0.041	0.030
Si	6.29	5.03	5.54	4.50	5.63	6.57	5.41

The average levels of potassium, calcium, and silicon were lower in the October planting than in the other plantings.

In the July planting, the contents of potassium, iron, manganese, and silicon were higher than those in the other seasons.

The content of all mineral elements, except nitrogen, was within the normal range at all stages of growth, indicating that there was neither a deficiency nor an excess of any of these elements.

Removal of Nutrients from the Field

The amounts of nutrients at harvest in plants of each variety in each season were calculated. No consistent differences were noted among varieties or among seasons.

With this information, the overall average amounts of nutrients removed from the field were determined (Table 1.12).

The amounts of silicon and potassium in the

Table 1.12. Average Amounts of Nutrients Removed by a Rice Crop, IRRI, 1962-1963.

Nutrient	Amount of nutrient (kg/ha) removed by one crop[a]		Amount of nutrient removed by 1 ton of rice (kg)	
	Total	Panicle	Total	Panicle
N	90	48	19	10
P	20	12	4.3	2.7
K	219	11	47	2.3
Ca	34	12	7.2	2.6
Mg	25	9	5.3	1.9
Fe	12	1.6	2.6	0.3
Mn	12	2.3	2.6	0.5
Si	829	173	177	37

[a] Average grain yield was 4.74 ton/ha.

plants were far greater than of the other elements. The magnitude of the removal of elements by a crop was of the following order: Si > K > N > P, Ca, Mg > Fe, Mn. The removal of elements such as silicon or potassium, which occur largely in the straw rather than in the panicle, is great in the case of varieties, such as Peta, with small panicle-straw ratios. Because of the unequal distributions of the elements in the straw and in the panicle, the order of removal of the grain alone was: Si > N > P, K, Ca, Mg > Fe, Mn.

The data indicate that the amounts of elements removed by harvesting greatly depend on the method of harvest. If the entire plant is harvested, a great amount of silicon and potassium is removed along with much nitrogen. But if only the grain is removed, large amounts of silicon and nitrogen are removed.

Discussion

Many reports (Sahasrabuddhe, 1928; Dastur and Pirzada, 1933; Ramiah and Narasimhan, 1936; Fujiwara, *et al.*, 1951; Ishizuka and Tanaka, 1952-1953, 1954; Arashi and Eguchi, 1954; Togari, *et al.*, 1954; Arashi, 1955; Takahashi, *et al.*, 1955; Tanaka, Patnaik, and Abichandani, 1959; Chiu, Lian, and Hsu, 1961; Ishizuka and Tanaka, 1961; Kanapathy and Thamboo, 1961; Seetharama Rao and Krisna Rao, 1961) are available on growth and nutrient uptake processes of rice plants. Because of the diversity of varietal characters as well as of ecological conditions, more such studies are needed.

To observe the growth performance of tropical rice varieties at the Institute, Tainan-3, a non-photosensitive *japonica*, Peta, a weakly photosensitive *indica* with foliage typical of varieties popular in the tropics at present, and BPI-76, a photosensitive *indica*, were planted in four different seasons.

Data collected reveal that the growth of rice plants may be considered in four phases: Active-vegetative (transplanting to maximum tiller number stage); vegetative-lag (maximum tiller number to ear-initiation stage); reproductive (ear-initiation to flowering stage); and ripening (flowering to harvest).

It has been stated that the growth of a *japonica* variety in the temperate climate area has three phases – vegetative, (vigorous development of leaves, tillers and roots), reproductive (active differentiation and development of reproductive organs and rapid elongation of internodes), and ripening (development and ripening of kernels) (Ishizuka and Tanaka, 1952-1953, 1954; Nagai, 1958). In this study, however, it became apparent that if the growth duration of a plant is long, there is a long lag period between the maximum tiller number stage and the ear-initiation stage. During this period, rice plants perform quite differently than at the tillering stage. On this basis, the vegetative phase is better subdivided into two phases – the active-vegetative and the vegetative-lag phases.

There are large differences in growth duration among varieties and among seasons; these are mainly associated with differences in the length of the vegetative-lag phase. It has been reported that in early varieties, ear-initiation closely follows the maximum tiller number stage, while in the case of medium and late varieties, ear-initiation may occur from a few to many weeks after the maximum tiller number stage is completed (Ramiah and Narasimhan, 1936; Tanaka, Patnaik, and Abichandani. 1959).

The duration of the active-vegetative phase is primarily a function of the amount of nitrogen available to maintain the nitrogen content in the plant above a critical level. Tillering is closely related to nitrogen content of the plant, especially to the soluble nitrogen in the culm (Oshima, 1962b). Under the conditions of this experiment, this critical nitrogen content of the straw was about 1.7 percent; this is similar to a previously reported value (Tanaka, Patnaik, and Abichandani, 1959).

A combination of varietal characters and climatic conditions, especially day length and temperature, determine the duration from sowing to ear-initiation. The extent to which growth duration changes with nutrient condition is limited in comparison to that conditioned by climatic factors (Tanaka, 1958b).

As the amount of nitrogen available to the plant, the varietal characters, and the climatic conditions are independent factors, the duration of the vegetative-lag phase varies. The longer the total growth duration, the longer the vegetative-lag phase. If the total growth duration is extremely short, the reproductive phase and the active-vegetative phase overlap (Ishizuka and Tanaka, 1961). The optimum growth duration of present ordinary varieties under general field conditions seems to be approximately 130-140 days, in which case, there is almost no vegetative-lag phase (Ishizuka and Tanaka, 1961). Recent evidence indicates

that varieties of even shorter duration may be necessary to obtain high yields per hectare per day; if properly spaced, these would have no vegetative-lag period.

Tainan-3 is a non-photosensitive variety. The variety performs fairly constantly with fairly good yields in any season. The period of growth is somewhat longer in the dry season because of the lower temperature. Tainan-3 is non-seasonal at the Institute, with a growth duration of 125-135 days and it produces a constant grain yield in any season. This wide adaptability of "ponlai" varieties indicates a promising future for this group in the tropics (Oka, 1961).

Peta is a weakly photosensitive variety. Because of the relatively small fluctuation in day length during the year at the Institute and the counteracting effect of cool temperature on the effect of the short winter day length, the growth duration is constant throughout the year. Thus, at the Institute, this is a non-seasonal variety with a growth duration of 135-150 days. Although there is little fluctuation in growth period, the grain yield differs greatly with the season. The variety yields well in the dry season, but not in the rainy season.

BPI-76 is a strongly photosensitive variety and the fluctuation of day length at the Institute causes marked differences in its growth duration among seasons. The maximum yield was obtained when it had a growth duration of approximately 170 days. It is suitabble for planting during the early part of the rainy season when the day length is long.

Each of these varieties produced at least 5 tons/ha per crop when planted in its optimum season.

One measure of the productivity of a crop is the grain yield per unit area per day in the main field. In experiments described here Tainan-3 produced about 50 kg/ha/day in each season. In the dry season, Peta produced about 54 kg/ha/day; however, in the other season the productivity of Peta was about 30 kg/ha/day. In the May planting, BPI-76 produced more than 5 tons/ha; however, because of its long growth period, the productivity of the crop was 37 kg/ha/day. In this sense, BPI-76 is not a good variety in any season.

As these figures demonstrate, the grain yield per crop and the grain yield per day are different topics. To obtain the maximum yield from a field in a given period of time, varieties must be used which produce high yields per hectare per day.

The growth rate of Peta is far greater than the other varieties in the early stages of growth. However, the rapid growth rate in the early stages is followed by a slower growth rate at later stages when the ear-primordium is developing or when the grains are ripening. Thus, Peta has a small panicle-straw ratio, particularly if grown during the rainy season. This type of growth is common among *indica* varieties of the tropics (Kanapathy and Thamboo, 1961). It appears that with active growth at the early stages, the field becomes crowded and, at later stages of growth, photosynthetic activity becomes weak in relation to respiration activity (Takeda, 1961). In the dry season, the growth rate of Peta at the early stages is low, probably because of lower temperature, and its grain yield is quite high.

Grain yield is the product of total plant weight and the grain-total weight ratio, and it is important that these two factors be balanced.

In the rainy season, BPI-76 gives a high yield because of its high total plant weight developed over a long period of vegetative growth. However, the panicle-straw ratio is small and the yield per day is low. In spite of a high panicle-straw ratio in the dry season, the yield is low because the total weight is small, the result of short duration.

Peta in the rainy season produces many tillers and long leaves at early stages of growth. The early vigorous growth causes serious mutual shading at conventional field spacing, allowing only a small portion of light falling on the field to enter the plant population. On the frequent rainy or cloudy days, less light is supplied to the plants. After the maximum tiller number stage, when the field becomes quite crowded, the limited supply of light at the base of the plants results in marked elongation of the lower internodes. The longer the vegetative-lag phase, the greater the number of elongated internodes and the longer the total length of the elongated internodes. The general pattern of internode elongation is similar to that previously reported for *japonicas* (Arashi and Eguchi, 1955) except for the elongation of a few lower internodes before the ear-initiation stage. These elongated lower internodes result in taller plants and serious lodging.

The serious mutual shading in Peta fields during rainy seasons results in the death of many weak tillers and lower leaves; consequently, the effective

tiller percentage of Peta in rainy seasons is extremely low. Many lower leaves are dead at flowering, a late stage in the growth period. The weight of dead leaves is a major fraction of the total straw weight. This is one of the most noticeable and important characters of ordinary *indica* varieties in the tropics. A comparison of rice plants in the north and south of Japan indicated that more dead leaves occur in the south than in the north (Ishizuka and Tanaka, 1961).

Tainan-3 which produced good yields in all four seasons also had 15 leaves on the main culm in each season, the longest leaf being the second and third from the flag-leaf. These long upper leaves are active when the variety flowers, indicating that nutrition was adequate to the end of growth. On the other hand, Peta in the rainy season had 21 leaves on the main culm and the longest leaf was the fifth from the flag-leaf. The growth of a leaf is affected by the nutritional status of the plant at the time the leaf is developing (Tanaka, 1961). At the flowering stage of Peta, these long leaves were dead and only a few short leaves at the top were active. It is apparent that the variety suffers from lack of nitrogen and/or light at the later stages of growth.

At the flowering stage, Tainan-3 had more active leaves than Peta, also the light transmission ratio was better in Tainan-3 than in Peta. Consequently, the photosynthetic activity of Tainan-3 was greater than that of Peta. Thus, in Tainan-3, a high proportion of the starch in the grain was produced after flowering. In Peta, with its fewer active leaves and greater mutual shading, photosynthetic activity at flowering was weak and little of the starch in the grain was produced after flowering. Peta in the dry season had a plant quite similar to that of Tainan-3; this explains why Peta produced higher grain yields in the dry season than in the rainy season.

The number of leaves on the main culm of the photosensitive BPI-76 changed significantly from season to season depending upon growth duration. More leaves were produced in the rainy season as a result of the long duration of the variety; however, the number of dead lower leaves at flowering also was greater. Thus, there were fewer active leaves at flowering in the rainy season. Nevertheless, BPI-76 gave its maximum grain yield in the rainy season, indicating that grain development largely depends upon substances stored in the straw before flowering rather than upon the products assimilated after flowering. This may explain why this variety has a long optimum growth duration.

The active nitrogen uptake at early stages of growth, as found for Peta in this study, is characteristic of the typical *indicas* and this is correlated with their low nitrogen response character (Matsuo, 1952; Takahashi, Iwata, and Baba, 1959). During the period when nitrogen uptake is vigorous, the carbohydrate content of the plants is relatively low, indicating that most assimilation products are used in nitrogen uptake and plant expansion. This causes rapid plant growth at early stages. Later, the nitrogen uptake falls off, and nitrogen and other nutrient elements are lost from the plants at later stages of growth. The loss results from heavy mutual shading and occasional heavy rains which limit the supply of energy to the lower leaves (Tanaka and Navasero, 1964). In contrast to the loss of nitrogen, a significant accumulation of carbohydrates in the straw occurs after ear-initiation (Yamada, 1959). Grain development in such *indicas* largely depends upon the nitrogen and carbohydrate stored in the straw before flowering. In *japonicas,* 15-30 percent of the starch in the grain at harvest previously was stored as carbohydrate in straw; in Peta, in the rainy season, the value was more than 60 percent.

In Tainan-3 nitrogen uptake is slow at early stages of growth, but it continues until harvest. The percentage of carbohydrates at early stages is relatively high, indicating that some of the assimilated energy is stored as starch instead of being used for nitrogen uptake and expansion of plant. On the other hand, the percentage of carbohydrates in the plant at flowering is relatively low. Much of the starch accumulated in grain is assimilated after flowering. Although the early growth of Tainan-3 is not rapid, it remains active to the end of growth.

When planted in the rainy season, BPI-76 has a long growth duration, and under such conditions, the nitrogen uptake of this variety differs from the others. Nitrogen uptake is active at the early stages, slows down during the vegetative-lag phase, and then again becomes active during the reproductive phase. This pattern is characteristic of varieties of long growth duration (Tanaka, Patnaik, and Abichandani, 1959). The reason for

the second period of active nitrogen uptake is not known. When BPI-76 has a long growth duration, grain development completely depends upon substances stored in the straw before flowering. Because of the large amount of straw developed during the long growth period and because of the large amounts of starch stored in its thick culms, grain yields are comparatively high.

In the dry season, the growth duration of BPI-76 is short, much nitrogen is absorbed after flowering, and photosynthetic activity is active until harvest. But with the short growth duration, the leaf area at flowering is limited, and the yield is not great at conventional spacings. These types of changes caused by different seasonal plantings illustrate the relationship between growth performance and growth duration (Vergara, Lilis, and Tanaka, 1964).

Tainan-3 has a higher silicon content than the other two varieties. The erectness of leaves can be increased by increasing the silicon content (Iwata and Baba, 1962). This suggests that the high silicon level in Tainan-3 may be related to its erect leaf habit. Peta is higher in potassium content than the other varieties, especially Tainan-3. This may be related to the more succulent character of the straw of Peta. The high iron and manganese levels in Tainan-3 may be related to the darker color of the variety.

The character of elements in connection with the growth processes of the plant can be considered under the following: (1) uptake process with growth, (2) losses from the plant at later stages of growth, (3) trans-location from the lower dead leaves to the upper active organs, and (4) translocation from the straw to the developing grain.

Nutrient elements can be characterized as follows:

Nitrogen and phosphorus. These are absorbed vigorously at the early stages of growth, then the rate decreases with growth. Under certain conditions, these elements are lost from the plants at later growth stages if mutual shading becomes serious. These elements translocate efficiently from the dying lower leaves to the upper active organs, and a major portion of these elements translocate to the grain during ripening.

Potassium. The absorption is active at the early stages of growth and this continues until harvest. Under some conditions, large losses from the plant occur at larger stages. Translocation from dying lower leaves to the upper active organs is efficient, but translocation to the developing grain is limited.

Calcium and magnesium. Absoption approximately parallels dry matter increase. After flowering, these elements may be leached out to some extent. Translocation from the old to new leaves is not significant and the proportion of these elements in the grain is not as large as nitrogen or phosphorus. Translocation of magnesium exceeds that of calcium.

Iron, manganese, and silicon. Absorption is rather slow at the early growth stages, but this continues until harvest. There is no translocation from old leaves to young organs. Proportions in the panicle are relatively small.

These characterizations are similar to those previously made using *japonica* in the temperate climate area (Ishizuka and Tanaka, 1952-1953, 1954). In the present studies, however, differences between the *indica* and the *japonicas* have been noted. The statements in this report are based on the studies with both *indicas* and *japonicas* in the tropics and with *japonicas* in Japan. Thus, these statements are more generally applicable than ones previously made (Ishizuka and Tanaka, 1952-1953, 1954).

At the early stages of growth, nutrient levels in the soil are high, and the metabolic activity of roots is active. Thus there is rapid uptake of nutrients, especially those absorbed metabolically such as nitrogen, phosphorus, and potassium (Mitsui, 1960). The energy assimilated by the plant is used mostly for nutrient uptake, protein synthesis, and plant expansion and little energy is stored as starch.

After the maximum tiller number is reached, the levels of some nutrient elements, especially nitrogen, in the soil decrease, and the metabolic activity of the roots decreases. Uptake of nutrients such as nitrogen, phosphorus, and potassium falls off, resulting in less synthesis of protein and more accumulation of starch. Those early and later stages of growth have been designated as the "protein phase" and the "carbohydrate phase," respectively (Fujiwara, *et al.*, 1951).

From the information obtained with various annual plants, three conspicuous stages of growth were identified (Loehwing, 1953):

1. The initial anabolic phase in which uptake of inorganic nutrients and synthesis of protein is rapid.

2. The second phase, characterized by the acceleration of carbohydrate accumulation and the gradual diminishing of the rate of protein synthesis.

3. The catabolic phase, in which hydrolysis of reserves begins to outbalance synthesis and a general internal redistribution of nutrients is initiated.

These three phases correspond to the active-vegetative phase, the reproductive phase, and the ripening phase, respectively, as defined in this bulletin.

Except for nitrogen, the levels of the various nutrients in the straw of all varieties in all seasons were within normal limits. Thus it was not possible for these elements to change in the growth pattern of the plant. At the Institute, it is not necessary to apply nutrients other than nitrogen to the rice plant planted in the fields.

The removal of nutrients by the rice plant which produces 1 ton of rice grain is estimated at about 180 kg of Si, 50 kg of K, 20 kg of N, and 3 to 7 kg each of Ca, Mg, P, Fe, and Mn. These values for nitrogen, phosphorus, calcium and magnesium removal are within the ranges reported in various countries; however, the potassium value is somewhat larger than reported elsewhere (Glander, 1957; Kanapathy and Thamboo, 1961). The removal of potassium is probably related to the high potassium level of the soil. The removal of silicon, potassium, and nitrogen is substantial, and soil levels of these nutrients will steadily decline unless applied. Because of the big proportion of straw, the removal of silicon or potassium by 1 ton of rice is high in *indicas* if straw is removed from the field along with grain. If most of the straw is left in the field, removal per ton of rice grain becomes: Si, 37 kg; N, 10 kg; P, K, Ca, and Mg, less than 3 kg; Fe and Mn, 0.5 kg. Under ordinary field conditions removal of nitrogen in the grain is significant; removal of other elements is not.

Part II

Relationship of Varietal Characters to Nitrogen Response with Special Emphasis on Mutual Shading

The general trend in rice cultivation in most countries is to apply more fertilizers, especially nitrogenous, in attempts to obtain higher grain yields. Varietal differences in nitrogen response often have been reported, and the importance of breeding varieties with high nitrogen response emphasized (Matsuo, 1952; Oka, 1954; Baba, 1954, 1961; Tanaka, 1958a; Evatt, Johnston, and Beachell, 1960; Beachell and Evatt, 1961; Chandraratna, 1961).

Part I reported the differences in nitrogen absorption obtained with three varieties grown in various seasons in the tropics. These differences were related to growth habit which, in turn, was affected by response to photoperiod, temperature, and amount of light.

The term "nitrogen response" conceivably could be used to refer to any of several characteristics of rice plants, and it seems desirable to clarify its use in this report. As the farmer seeks to produce a high yield of grain, grain yield is a logical indicator of response.

The quantity of grain produced per unit of applied nitrogen also is a critical factor; consequently, varieties are desired which *utilize nitrogen efficiently in the production of high grain yields.*

Data in Part I indicated that although tall, late *indica* varieties in the tropics may absorb nitrogen rapidly and have high nitrogen levels in plant tissues, they may produce low grain yields, particularly in terms of production of grain per unit area per unit of time. Such varieties have low response. Some varieties may respond to nitrogen applications by producing substantially increased grain yield, but if the total yield is small, particularly in terms of yield per unit area per unit of time, the variety probably should not be considered highly responsive.

High-yielding varieties which most efficiently use nitrogen in producing high grain yields are considered highly responsive.

In Southeast Asia, the use of nitrogenous fertilizers has been slight. Varieties grown in this area appear adapted to low nitrogen level conditions. But in the temperate areas where large amounts of nitrogenous fertilizers have been used, varieties have been developed for, and are adapted to, high nitrogen levels. As *indicas* and *japonicas* are cultivated in the tropics and in temperate areas, respectively, it generally is considered that *japonicas* respond to nitrogen better than *indicas*. In Taiwan, the response to nitrogen generally is less in the native varieties (*indicas*) than in the ponlai varieties (*japonicas*) (Proc. Symp. of Studies on the Causes of Low Yields of Rice in Tropical Regions and Sub-tropical Regions, 1961). Consequently, *japonica* x *indica* hybridization has been used to breed high-nitrogen-response varieties (Report, 2nd Meeting, IRC Working Party on Rice Breeding, 1951). But certain *indicas* exhibit high nitrogen response (Report, 2nd Meeting, IRC Working Party on Rice Soils, Water, and Fertilizer Practices, 1961).

In Southeast Asia, most rice is grown during the period of monsoon rains; thus, during the main rice season the number of sunny days is limited. As carbohydrate and nitrogen metabolisms are closely related, a shortage in assimilation products resulting from the limited sunlight may be related to the limited response of rice plants to nitrogen application in the tropics.

Higher temperatures in the tropics than in temperate areas may also result in lower nitrogen response. The reasons for this low response must be understood if rice cultivation in this part of the world is to be improved. The following is a brief review of available information on this subject.

Yield Components

The yield of rice plants may be described as the product of the yield components, i.e., the number of panicles per unit field area, the number of spikelets per panicle, percentage of filled grain, and the mean grain weight (1,000-grain weight).

Rice varieties are classified broadly into "panicle weight" and "panicle number" types (Baba, 1956). As the number of panicles varies more than panicle weight (Ramiah and Narasimhan, 1936), it generally has been considered that the panicle number type responds to nitrogen better than the panicle weight type. The rate of increase of panicle number with increases in nitrogen application is reported to be lower in *indicas* than in *japonicas* (Oka, 1956). Tillering is positively correlated with nitrogen content of the plants (Oshima, 1962b) and is more closely correlated with the nitrogen content of the stem (Takahashi, *et al.*, 1956). Tiller number is important in determining panicle number, although the percentage of effective tillers is as important.

Many reports indicate that with increasing nitrogen supply during the ear-primordium deve-

lopment, the number of spikelets per panicle increases.

When the number of panicles as well as the number of spikelets per panicle increases, the number of spikelets per unit area increases; however, the percentage of filled grain tends to decrease beyond a certain limit of nitrogen supply. Thus the number of filled grains produced per unit field area is limited.

It is reported that 1,000 grain weight has little relation to nitrogen supply (Baba, 1956). If the nitrogen level is extremely high, however, the 1,000-grain weight decreases with increases in nitrogen application, particularly in low-response varieties (Tanaka, Patnaik, and Abichandani, 1958).

Two factors determine the yield of rice plants, i.e., total volume of the spikelets in which starch may accumulate, and the amount of starch which actually accumulates in the spikelets. The former generally is increased by nitrogen applications. The latter does not necessarily increase with increases in nitrogen level. Hence, at high nitrogen levels the percentage of filled grain is low, and the mean grain weight is small. These contradictory relationships among yield components affect the optimum nitrogen level and suggest reasons for varietal differences in nitrogen response.

Photosynthesis and Plant Type

Leaf characters associated with photosynthesis are correlated with nitrogen response (Murata, Osada, and Iyama, 1957).

Total photosynthesis by rice plants per unit field area (P_1) can be expressed as the product of the photosynthetic activity per unit of leaf area (P_o), total leaf area per unit of field area (leaf area index or LAI), and "light-receiving" coefficient (f):

$$P_1 = f \cdot LAI \cdot P_o$$

At a low nitrogen level, the LAI is small and f remains constant; an increase in the LAI proportionally increases photosynthesis. At a high nitrogen level, however, the LAI is large, resulting in mutual shading which decreases the f value; hence, an increase in the LAI does not proportionally increase photosynthesis.

The light intensity at the base of a community of rice plants (I) is determined by the LAI and the extinction coefficient (K). The I value when the light intensity above the community is I_o is expressed by the following formula (Monsi and Saeki, 1953).

$$I = I_o \cdot e^{-K \cdot LAI}$$

$$\therefore K = \log e \frac{I}{I_o} / LAI$$

I/Io is referred to as the light transmission ratio.

Dry matter production depends upon the balance between photosynthesis (P_1) and respiration (R). Because of the nature of f, P_1 does not increase in proportion to the LAI if the LAI is large. But R increases in proportion to the LAI; therefore, there is an optimum leaf area for maximum dry matter production. An increase in leaf area does not always result in an increase in dry matter if I_o is small (Takeda, 1961).

Breeders claim that varieties adapted to low nitrogen levels are characterized by long, broad, thin, drooping, and pale green leaves extending almost horizontally. They speculate that this character of the leaves enables the plants to use light more efficiently under low nitrogen conditions. At high nitrogen levels, at which the LAI tends to be large, a variety with horizontal leaves suffers seriously as the upper leaves shade lower leaves. Varieties suitable for heavy nitrogen applications are reported to have small, thick, dark green, and erect leaves (Tsunoda, 1959-1960; Murata, 1961; Jennings, 1964).

Varieties with a plant habit which permits a high light transmission ratio usually respond well to nitrogen (Murata, 1961). It was pointed out that with increasing nitrogen applications the rate of increase in photosynthetic activity (P) is greater in high-response than in low-response varieties. But the rate of increase in respiration (R) is greater in low-response varieties.

The ratio P/R at high nitrogen levels is higher in high-response varieties than in low-response types (Osada and Murata, 1962).

With heavy nitrogen fertilization, the development of leaves is vigorous during the vegetative period; consequently, the leaf area becomes large at the later stages of growth, and the luxuriant leaves of low-response varieties seriously shade each other in a community condition. Therefore, the actual rate of photosynthesis is not as high as the leaf area would suggest. Respiration of plants increases markedly with an increase in nitrogen supply regardless of the degree of mutual shading. Therefore, net gain in assimilation products (P-R)

decreases if the nitrogen supply is too large (Kumura and Takeda, 1962).

An increase in nitrogen level causes a decrease in the silica content of plants, making the leaves more droopy (Ishizuka and Tanaka, 1950a). Application of silica may make photosynthesis more active at a high nitrogen level by making the leaf more erect (Iwata and Baba, 1962).

Grain-Straw Ratio

Total dry matter production is not directly related to grain production, but the grain-straw ratio is important in determining grain yield.

Straw weight increases with amount of nitrogen applied. Grain weight also increases with nitrogen applications up to a certain level; above the critical level, grain weight decreases.

For this reason, the grain-straw ratio generally decreases with increases in applied nitrogen. This decrease is more prominent in low-nitrogen-response varieties (Tanaka, Patnaik, and Abichandani, 1958). An increase in nitrogen level favors vegetative growth in both low- and high-response varieties, but there are marked varietal differences in growth during the reproductive stage. As has been discussed, there is little or no mutual shading at early stages of vegetative growth, but it may become quite important when reproductive growth is taking place.

The starch which accumulates in the grain comes from two sources — starch accumulated in the straw before heading and from products assimilated after heading. With low nitrogen, the former provides as much as 40 percent of the total starch in the grain but with a high nitrogen level it provides less than 10 percent (Murayama, *et al.,* 1955). This seems to have an important bearing on changes in the grain-straw ratio as the nitrogen level varies.

The translocation of assimilation products from the straw to the panicle reportedly is slower in a plant receiving a high level of nitrogen than in one receiving a low level (Oshima, 1962a). The rate of increase in grain weight during the early stage of ripening is small, but it becomes large at the later stages. The ripening period lasts longer in highly responsive varieties than in low-response types; this allows more complete translocation of assimilation products from straw to grain (Tsunoda, 1962).

Nitrogen Uptake and Metabolism

With high nitrogen levels, low-response varieties absorb nitrogen more actively than high-response varieties during the early stages of growth, but the active nitrogen absorption later is suppressed (Matsuo, 1952; Takahashi, Iwata and Baba, 1959). Excess uptake of nitrogen causes a decrease in carbohydrate content while a limited uptake of nitrogen causes an accumulation of assimilation products, such as starch (Fujiwara, *et al.,* 1951; Takahashi, *et al.,* 1955). In the vegetative stage, low-nitrogen-response varieties contain less starch than high-response varieties. Accumulation of starch in the straw decreases with increases in nitrogen supply. This is more conspicuous in low-response varieties because of their greater absorption of nitrogen and greater increase in growth rate and leaf area. At the reproductive stage, the previously big differences among varieties in starch content diminish (Tanaka, 1958a; Takahashi, Iwata, and Baba, 1959).

Total nitrogen content in the plant increases with an increase in nitrogen supply. Protein nitrogen does not increase as significantly as non-protein soluble nitrogen; so, the soluble-to-protein nitrogen ratio increases with an increase in nitrogen supply (Ishizuka and Tanaka, 1950b). It has been reported that at a high nitrogen level, low-response varieties accumulate more soluble nitrogen at the early stages of growth, resulting in a higher ratio. This accumulation of excess soluble nitrogen in low-response varieties usually is followed by suppressed absorption of nitrogen at later stages of growth (Matsuo, 1952).

However, another report indicates that a marked difference in the soluble nitrogen-protein nitrogen ratio occurs only at the reproductive stage, not at the vegetative stage (Tanaka, Patnaik, and Abichandani, 1958).

Rice plants contain various free amino acids and amides. There are two amides that predominate, i.e., glutamine and asparagine. Glutamine is always found in the rice plant, but asparagine is found only when rice plants are supplied with excessive nitrogen (Ozaki, 1954). It is reported that, under high nitrogen levels, low-response varieties contain larger amounts of asparagine than high-response ones.

The length of roots decreases with increases in nitrogen level in the culture media. The roots of low-response varieties are larger than those of high-response varieties at low nitrogen levels. The

decrease in root development resulting from an increase in nitrogen level is much more prominent in low- than in high-response varieties (Tanaka, Patnaik, and Abichandani, 1958).

The physiological activity of roots can be expressed by its ability to oxidize α-naphthylamine (Yamada and Ota, 1958). With heavy nitrogen applications, low-response varieties show higher root activity than high-response varieties at the early growth stages, but the activity decreases remarkably after a certain stage (Baba, 1954). This agrees with the vigorous uptake of nitrogen at the early stages and its retarded uptake at later stages, as reported in Part I.

In a low-response variety, the retarded uptake of nutrients at later growth stages may be related to serious mutual shading of the lower leaves. When stem elongation starts, roots receive assimilation products from the lower leaves but not from the upper leaves (Tanaka, 1961). Lower leaves are not photosynthesizing because of low light intensity and the energy supply reaching the roots is limited. The death of the lower leaves seriously affects nutrient uptake (Araki, 1962).

Lodging is closely related to the decreases of yield which accompany excess nitrogen application. The height of plant increases, the thickness of the stem decreases, and leaves become heavier with increases in applied nitrogen. Consequently, a high nitrogen supply aggravates lodging.

Because the culm is composed mainly of cellulose and lignin, the decrease in the amount of these components with an increase in nitrogen supply results in the weakening of the culm. This leads to lodging (Kono and Takahashi, 1961). It is reported that lodging usually occurs after heading when there is a decrease in the starch content of the basal portion of the culm (Sato, 1957). Resistance to lodging positively correlates with starch content in the culm and leaf sheath (Takahashi, *et al.*, 1955). Low starch content is expected if the nitrogen level is high. Poor root development at a high nitrogen level also may be related to lodging susceptibility.

Low-response varieties seem more leafy than high-response ones. In low-response varieties, serious mutual shading caused by heavy nitrogen application results in an adverse effect of nitrogen on grain production. Because empirical support for this hypothesis was lacking, a series of experiments was conducted.

Varietal Response to Nitrogen Under Field Conditions (Experiment 1)

An initial experiment was designed to determine if there are varietal differences in nitrogen response under ordinary field conditions at the Institute and, if so, which varietal characteristics are related to nitrogen response.

Method

Thirteen varieties from several countries were selected on the basis of available information about their response to nitrogen (Table 2.1).

Seeds were sown July 3, 1962, and transplanted July 14. Two nitrogen levels, 0 and 100 kg/ha, were used. Just before the final puddling, phosphorous (P) and potassium (K) were applied uniformly at 17 and 33 kg/ha, respectively.

A split plot design with two replicates was used, with nitrogen levels as the main plots. The spacing was 30 x 30 cm with one plant per hill.

Notes and samples were taken August 13 (30 days after planting), September 5 (53 days after planting), at flowering, and at maturity.

Table 2.1. Yield of Dry Grain in Tons per Hectare of 13 Varieties at No and 100 kg/ha Added Nitrogen, IRRI, 1962 Wet Season.

Type and variety	Country of origin	Grain yield (ton/ha) N level (kg/ha) 0	100	Response to nitrogen (ton/ha) (100-0)	Days to maturity
Japonicas					
Kinmaze	Japan	1.99	2.31	0.32	100
Norin 25	Japan	1.92	2.02	0.10	100
Fujisaka 5	Japan	2.80	2.99	0.19	100
Norin 8	Japan	1.85	2.10	0.25	100
Tamanishiki	Japan	1.91	2.37	0.46	100
Obanazawa	Japan	2.35	3.12	0.77	100
Chianung 242	Taiwan	4.70	5.18	0.38	118
Tainan-3	Taiwan	5.34	5.54	0.20	118
Indicas					
Taichung (Native) 1	Taiwan	4.83	6.02	1.19	108
Century Patna 231	U.S.A.	3.39	4.66	1.27	108
Peta	Philippines	2.48	2.10	-0.38	141
59-368	Ceylon	1.98	1.17	-0.81	141
Acheh Puteh	Malaya	3.01	1.95	-1.06	141
LSD				0.42	

Results

Grain Yield

For grain yield, varietal differences and the variety x nitrogen interaction were highly significant. The effect of nitrogen was not significant. (Table 2.1).

The high yields without additional nitrogen indicate the high nitrogen level of the soil.

The yields at 100 kg/ha N of varieties Peta, 59-368, and Acheh Puteh were lower than when no additional nitrogen was applied; all other varieties gave higher yields at 100 kg/ha N. The yield increases in Taichung 1 and CP-231 were greatest.

The grain yields of the Japanese varieties were low compared with their yields in Japan. These varieties obviously are not well adapted to the environmental conditions at the Institute.

The *japonicas* did not necessarily respond to nitrogen better than *indicas.* Some *indicas,* such as Taichung 1 and CP-231, responded well to nitrogen. The differences in nitrogen response among *japonicas* were small in comparison to the wide differences among *indicas.* None of the *japonicas* gave negative responses as did the *indicas,* Peta, 59-368, and Acheh Puteh.

Plant Type

Plants were taller at the high nitrogen level than when no additional nitrogen was applied (Table 2.2). The varieties from Japan were extremely short. The three low-response *indicas* were taller than the other varieties, and with or without nitrogen they lodged before flowering. Tallness and lodging susceptibility appear to be closely related to the low-nitrogen-response character.

The panicle number at harvest increased with nitrogen level, particularly in the varieties from Japan.

Taichung 1 had many tillers while CP-231 had the least (Table 2.2); yet, both these varieties responded well to nitrogen, indicating that some panicle-number types as well as panicle-weight types have high nitrogen response. In the three low-response varieties, increased nitrogen resulted in little or no increase in effective panicle number at harvest.

The panicle-straw ratio of high-yielding varieties was large and that of low-response varieties small. The ratios of high-nitrogen-response varieties increased with increase in nitrogen application, but diminished in the case of the three low-response varieties (Table 2.2).

Table 2.2. Height, Panicle Number, Total Dry Weight, and Panicle-straw Ratio at Harvest of 13 Varieties Grown at No and 100 kg/ha Added Nitrogen, IRRI, 1962 Wet Season.

Variety and nitrogen level (kg/ha)	Height (cm)	Number panicle per hill	Total dry weight (g/plant)	Panicle straw ratio
Kinmaze				
0	77	52	61	0.69
100	81	60	82	0.71
Norin 25				
0	79	55	67	0.82
100	80	62	75	0.81
Fujisaka 5				
0	88	38	63	0.81
100	92	44	74	0.96
Norin 8				
0	82	48	52	0.81
100	84	57	72	0.64
Tamanishiki				
0	81	47	52	0.89
100	88	49	55	0.80
Obanazawa				
0	94	21	59	1.01
100	103	37	75	0.92
Chianung 242				
0	138	15	109	1.17
100	141	19	124	1.27
Tainan-3				
0	137	19	104	1.37
100	141	28	133	1.13
Taichung 1				
0	117	24	100	1.08
100	125	33	115	1.32
CP-231				
0	136	8	60	0.73
100	157	13	113	0.89
Peta				
0	188	16	123	0.39
100	191	16	128	0.28
59-368				
0	205	18	128	0.41
100	213	20	138	0.32
Acheh Puteh				
0	206	15	133	0.37
100	207	17	134	0.28

Growth Process

At an early stage of growth, August 13, the low-response varieties – Peta, 59-368, and Acheh Puteh – had higher dry weights than other varieties, and there were greater differences in their dry weights with and without nitrogen (Fig. 2.1). The situation was similar to Septem-

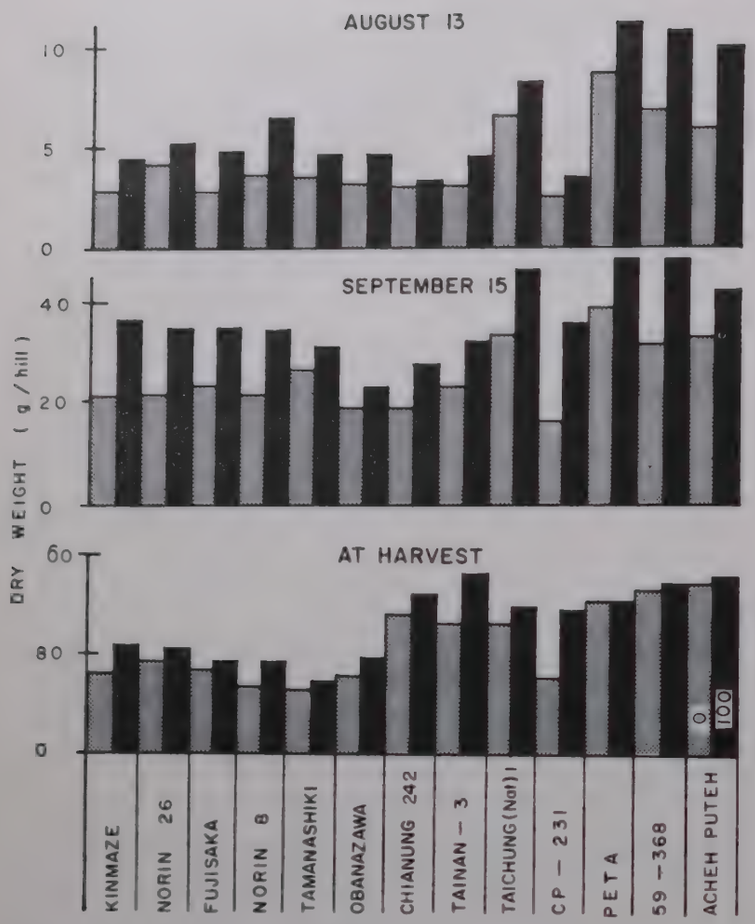


Figure 2.1. Dry weight at different stages of growth of 13 varieties grown with and without 100 kg/ha applied nitrogen, IRRI, 1962 wet season.

ber 15, but varietal differences were smaller. At this growth stage of the high-response varieties, the differences in dry weight associated with nitrogen levels were greater. At harvest in the high-response varieties, there were marked differences in dry weight which could be related to nitrogen level; but differences were negligible in the low-response varieties.

The low-response varieties grew faster at the early stages of growth than the high-response varieties, especially at the high nitrogen level. As a result of the early vigorous growth, the field became crowded even without additional nitrogen; as a result of this competition, there was no increase in dry weight with nitrogen application. Growth of the high-response varieties at the early stages was rather slow and the increase in dry weight caused by nitrogen application was not as remarkable; consequently, this type of variety had enough room at later stages of growth even when it received a high application of nitrogen.

On August 13, the tiller number of the low-response varieties was large, and application of nitrogen produced a notable increase (Table 2.3). The same trend was found in Taichung 1. CP-231 had fewer tillers than the other varieties.

The percentage of effective tillers was calculated assuming the maximum tiller number occurred September 15 (Table 2.3). The percentage of effective tillers of low-response varieties was relatively small, especially with the high nitrogen application.

Element Content

On August 13, varieties differed in total nitrogen content; the differences apparently were not

Table 2.3. Tiller Number per Hill at Various Stages of Growth of 13 Varieties Grown at No and 100 kg/ha Added Nitrogen, IRRI, 1962 Wet Season.

Variety and nitrogen level (kg/ha)	Tiller number per hill			Percentage of effective tillers
	Aug. 13	Sept. 15	At harvest	
Kinmaze				
0	10	30	52	—
100	14	42	60	—
Norin 25				
0	9	28	55	—
100	13	41	62	—
Fujisaka 5				
0	8	25	38	—
100	8	34	44	—
Norin 8				
0	11	34	48	—
100	15	38	57	—
Tamanishiki				
0	8	28	47	—
100	10	33	49	—
Obanazawa				
0	7	17	21	—
100	9	19	37	—
Chainung 242				
0	6	17	15	88
100	8	27	19	70
Tainan-3				
0	8	20	19	95
100	11	28	28	100
Taichung 1				
0	15	32	24	75
100	21	46	33	72
CP-231				
0	4	10	8	80
100	6	18	13	72
Peta				
0	19	33	16	49
100	29	43	16	37
59-368				
0	14	27	18	67
100	23	38	20	53
Acheh Puteh				
0	15	23	15	65
100	22	37	17	46

related to nitrogen response (Table 2.4). For example, the total nitrogen was highest in Taichung 1, which responded to nitrogen, while that of Peta, a low-response variety, was second. The varieties which were active in tillering had higher nitrogen content. Application of 100 kg/ha N resulted in increases in total nitrogen in the plant, but there were no interactions between varieties and nitrogen levels. There were some varietal differences in the soluble N-total N ratio but these were not correlated with nitrogen response either.

At flowering, there were significant varietal differences in nitrogen content of the straw, but these differences appeared to be related to duration. Hence, it is difficult to establish varietal differences.

The soluble N-total N ratios of low-response varieties, especially at the high nitrogen level, were slightly higher than those of other varieties.

The analyses of various elements were made on the August 13 samples from the 100 kg/N plot (Table 2.5). In low response varieties, phosphorus and silicon content tended to be relatively low and potassium content to be relatively high. The magnesium and manganese content of *japonicas* was higher than that of the *indicas,* but there was no apparent difference between low-response and high-response groups. The lower content of silicon in low-response varieties may be related to their relatively soft leaf character. The percentage of dry matter of the *indicas* was lower than that of the *japonicas;* the higher water content of *indicas* may be related to the succulence of their leaves.

Table 2.4. Total Nitrogen Content and Soluble Nitrogen – Total Nitrogen Ratio 30 days after Planting and at Flowering of 13 Varieties Grown at No and 100 kg/ha Added Nitrogen, IRRI, 1962 Wet Season.

Variety	Sampled August 13				Sampled at flowering			
	Total N (%)		Soluble N / Total N		Total N (%)		Soluble N / Total N	
	0	100	0	100	0	100	0	100
Kinmaze	2.72	2.95	0.16	0.16	1.98	1.90	–	–
Norin 25	2.64	2.72	0.17	0.19	1.85	1.84	–	–
Fujisaka 5	2.48	2.56	0.17	0.16	1.90	1.86	–	–
Norin 8	2.74	2.71	0.18	0.18	1.71	1.71	–	–
Tamanishiki	2.58	2.58	0.16	0.17	1.60	1.60	–	–
Obanazawa	2.31	2.47	0.16	0.18	1.77	1.80	–	–
Chianung 242	2.47	2.72	0.18	0.18	1.29	1.38	0.40	0.43
Tainan-3	2.50	2.66	0.18	0.18	1.20	1.35	0.42	0.41
Taichung 1	2.99	3.39	0.18	0.20	1.27	1.35	0.49	0.47
CP-231	2.53	2.71	0.21	0.19	1.40	1.31	0.46	0.48
Peta	2.96	2.98	0.19	0.22	0.83	0.80	0.54	0.55
59-368	2.58	2.69	0.22	0.20	0.66	0.53	0.38	0.55
Acheh Puteh	2.80	2.95	0.19	0.20	0.46	0.65	0.51	0.57

Table 2.5. Element Content, as Percentage of Dry Matter, 30 Days after Planting of 13 Different Varieties, IRRI, 1962 Wet Season.

Variety	Percentage of dry matter, by element							Dry matter
	P	K	Ca	Mg	Si	Fe	Mn	(%)
Kinmaze	0.34	3.39	0.27	0.24	5.27	0.08	0.060	15.2
Norin 25	0.32	2.41	0.27	0.25	5.37	0.11	0.055	17.0
Fujisaka 5	0.31	2.90	0.26	0.21	5.69	0.11	0.057	16.6
Norin 8	0.34	3.13	0.27	0.24	5.22	0.12	0.055	16.6
Tamanishiki	0.33	3.09	0.25	0.25	5.37	0.18	0.057	16.9
Obanazawa	0.31	3.17	0.28	0.26	5.55	0.12	0.052	15.8
Chianung 242	0.32	3.19	0.31	0.25	5.87	0.12	0.088	16.1
Tainan-3	0.29	3.00	0.25	0.19	5.92	0.11	0.048	15.2
Taichung 1	0.32	3.38	0.28	0.15	5.55	0.06	0.015	14.2
CP-231	0.33	3.28	0.25	0.21	5.55	0.13	0.045	14.6
Peta	0.29	3.64	0.28	0.16	4.89	0.08	0.030	14.2
59-368	0.29	3.56	0.28	0.16	4.94	0.09	0.022	14.9
Acheh Puteh	0.29	3.51	0.28	0.20	4.71	0.13	0.040	14.8

Leaf Color

The low-response varieties consistently displayed a lighter green color than the other varieties (Table 2.6). High-response *indicas* were dark green. These data indicate that varieties having darker green leaves respond better to applied nitrogen than do varieties with leaves of a lighter green color.

Crude chlorophyll content of the samples collected August 13 was determined (Table 2.6). Chlorophyll content appeared to be closely related to the degree of greenness.

The light transmission curves of the acetone extract from Taichung 1 and Acheh Puteh indicated that absorptions at 660 mu as well as at 240 mu were greater in Taichung 1 than in Acheh Puteh. Thus, it is probable that the varietal differences in color are mostly due to the differences in chlorophyll content of the leaves, as has been reported (Mizuochi and Fujiwara, 1962).

Leaf color apparently was not related to nitrogen content of the plant.

Summary

Evidently, *japonicas* do not necessarily respond to nitrogen better than *indicas.* Some *indicas* respond to nitrogen remarkably well, but the

Table 2.6. Leaf Color and Relative Chlorophyll Content of Leaf-blades of 13 Varieties Given 100 kg/ha Nitrogen, IRRI, 1962 Wet Season.

Variety	Degree of greenness of leaf[a] Aug. 13	Sept. 5	Relative chlorophyll content[b]
Kinmaze	2	3	88
Norin 25	2	5	79
Fujisaka 5	6	2	81
Norin 8	6	5	82
Tamanishiki	6	5	81
Obanazawa	10	9	76
Chianung 242	2	9	82
Tainan-3	2	5	86
Taichung 1	1	4	100
CP-231	6	1	76
Peta	12	13	74
59-368	10	12	76
Acheh Puteh	13	11	75

[a] Ratings of degree of greenness of the leaves were made visually by two persons on two replicates. Number 1 represents the deepest green color, while 13 indicates a light green color.

[b] Pigments were extracted with acetone from the leaf-blades of the August 13 samples, and the transmittance of 660 mμ was determined with a spectrophotometer. The data presented are relative to the value of Taichung 1.

variation in nitrogen response among *indicas* is great.

There are panicle-number types as well as panicle-weight types among high-response varieties.

Low-response varieties are tall, have a low percentage of effective tillers, are susceptible to lodging, produce much dry matter, and have a small panicle-straw ratio. They grow at a relatively high rate at early stages of growth, and the field may become crowded even without additional nitrogen. Dry weight and effective tiller number may not increase with high nitrogen applications as a result of the serious competition among plants.

Varieties which respond well to high levels of nitrogenous fertilizer were characterized by short stature, high panicle-straw ratios, high percentages of effective tillers, slower growth in early stages, lower potassium but higher silicon content of the straw, and a dark green color resulting from higher chlorophyll content.

Neither total nitrogen nor the soluble N-total N ratio appeared to be good indicators of the responsiveness of varieties.

Varietal Response to Nitrogen Under Pot Conditions (Experiment 2)

The low- and high-nitrogen-response varieties identified in the first field experiment differed in vegetative growth habit. The vigorous early growth of the low-response varieties resulted in a seriously crowded population of tall plants.

To determine if varietal differences in nitrogen response could be eliminated by giving sufficient growing space, a pot experiment was conducted in the greenhouse.

Method

The same 13 varieties were planted July 21, 1962, in pots containing 6 kg of dry soil. Each pot of two seedlings received a uniform application of 0.44 g phosphorus (P) and 0.83 g potassium (K). Five levels of nitrogen were included, i.e., 0, 0.5, 1, 2 and 3 g N per pot, as ammonium sulfate. All fertilizers were applied just before planting. Each treatment was duplicated.

The pots were arranged to provide sufficient light for each plant and about 70 cm apart at the later stages of growth. Wire frames were placed on each pot to prevent lodging.

Results

Weight of Panicle, Straw, and Roots

It is apparent that the varieties which had a low response under field conditions — Peta, 59-368, and Acheh Puteh — responded as well as or even better than other varieties (Fig. 2.2). The yields of these three varieties were high.

Again, the growth of the Japanese varieties was abnormal because of unsuitable climatic conditions.

Straw weight increased with increases in nitrogen application, and the weights of Peta, 59-368, and Acheh Puteh were far greater than those of other varieties (Table 2.7).

Root weight increased with increases in nitrogen level up to 2 g/pot; root weight then decreased. Peta, 59-368, and Acheh Puteh had much larger roots than other varieties.

With increases in nitrogen level the proportion of total weight accounted for by roots decreased; increases in proportion of straw compensated for the change.

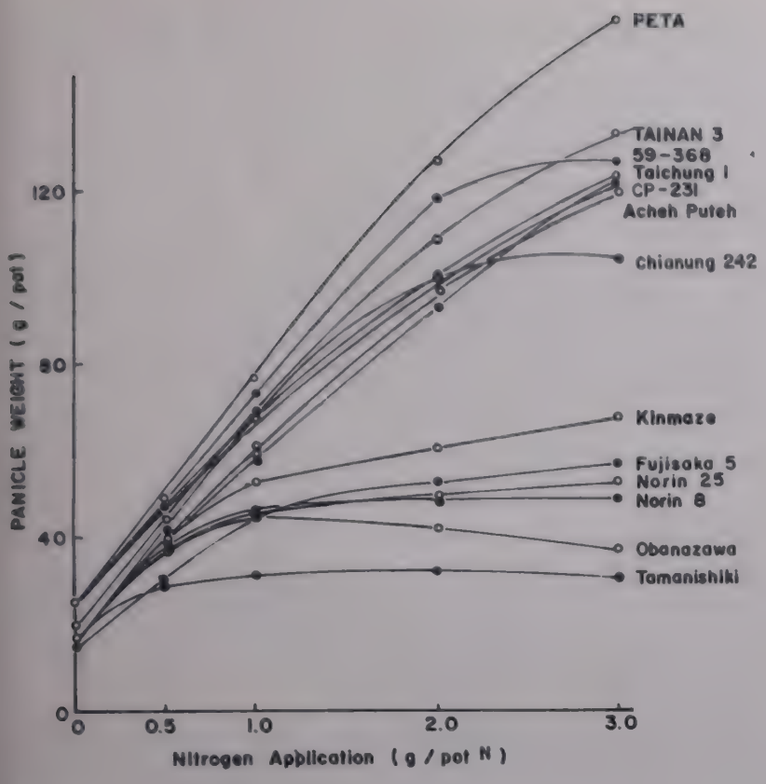


Figure 2.2. Effect of amount of applied nitrogen on panicle weight of 13 varieties grown in a greenhouse pot test, IRRI, 1962 wet season.

In the case of varieties having high nitrogen response under field conditions, the panicle weights were slightly less than the straw weights, and the root weights comprised less than 20 percent of the total. In the three varieties exhibiting low response under field conditions, the panicle weights were only about 25 percent of the total and the root weights accounted for 22-25 percent.

Yield Components

Panicle number and weight per panicle increased as nitrogen application increased (Table 2.8). The increase in the weight per panicle, however, was smaller than in the panicle number, as generally is the case.

Varieties having many panicles tended to have smaller panicles, and this is the basis for classifying rice varieties into "panicle number" or "panicle weight" types.

Among the *indicas*, Taichung 1 and CP-231 gave high response to nitrogen under field conditions. As Taichung 1 is a typical panicle number type and CP-231 is a typical panicle weight type, it is concluded that either type can respond well to nitrogen.

Table 2.7. Dry Weights of Panicles, Straw, and Roots at Harvest of 13 Varieties Grown in Pots at Varying Nitrogen Levels, IRRI, 1962.

Variety or N level	Dry weight (g/pot)			Percentage of total wt.			Days to maturity
	Panicle	Straw	Roots	Panicle	Straw	Roots	
Averages by variety							
Kinmaze	48	42	16	45	40	15	80
Norin 25	41	36	10	47	41	12	80
Fujisaka 5	40	35	11	47	40	13	80
Norin 8	39	32	7	50	41	9	80
Tamanishiki	27	33	9	39	47	14	80
Obanazawa	36	32	13	44	40	16	80
Chianung 242	61	84	32	34	47	19	108
Tainan-3	74	86	37	37	44	19	108
Taichung 1	67	74	24	40	45	15	97
CP-231	65	93	22	36	52	12	97
Peta	87	147	75	28	47	25	128
59-368	79	169	63	25	53	22	136
Acheh Puteh	69	146	70	24	51	24	136
Averages by nitrogen level (g/pot)							
0	17	21	17	31	38	31	—
0.5	39	53	31	32	43	25	—
1	56	76	33	34	46	20	—
2	78	107	38	35	48	17	—
3	91	132	30	36	52	12	—

Table 2.8. Yield Components of 13 Varieties Grown at Varying Nitrogen Levels in Pots, IRRI, 1962.

Variety or N level	Number panicles per pot	Weight per panicle (g)	Number spikelets per panicle	Filled grain (%)	1,000-grain weight (g)
Averages by variety					
Kinmaze	35	1.41	86	67	21.1
Norin 25	30	1.39	72	78	22.0
Fujisaka 5	25	1.57	84	73	23.4
Norin 8	30	1.32	71	72	24.0
Tamanishiki	29	1.02	67	57	24.3
Obanazawa	22	1.68	102	67	21.3
Chianung 242	20	2.87	134	84	25.9
Tainan-3	25	2.86	131	94	24.5
Taichung 1	31	2.20	112	84	21.3
CP-231	19	3.23	206	80	19.1
Peta	25	3.20	154	86	25.0
59-368	25	2.99	144	84	26.8
Acheh Puteh	22	3.03	173	88	21.4
Averages by nitrogen level (g/pot)					
0	9	1.98	99	86	23.0
0.5	23	1.88	103	78	22.9
1	27	2.17	112	77	23.5
2	33	2.20	138	74	23.1
3	39	2.50	139	74	23.0

In the pot test, the number of panicles of Taichung 1 increased as the nitrogen applications increased but the weight per panicle was hardly affected (Fig. 2.3). On the other hand, in CP-231 the number of panicles did not increase remarkably but the weight per panicle increased significantly. Varietal characters strongly influence the mode of response to nitrogen.

The number of spikelets per panicle increased and the filled grain percentage diminished with increases in nitrogen application. The 1,000-grain weight was fairly constant, regardless of the nitrogen level.

Nitrogen Percentage and Amount of Nitrogen Absorbed

The nitrogen percentage of the panicle, straw and roots increased with increases in nitrogen application, except for the first 0.5 where a slight decrease apparently took place (Table 2.9). Japanese varieties had high nitrogen percentage because of the smaller total weights reached during shorter growth periods. The nitrogen percentage of the straw of all other varieties was fairly low (lower than 0.7 percent) even with an application of 3 g/pot N, especially in Peta, 59-368, and Acheh Puteh (lower than 0.3 percent). This low nitrogen percentage indicates that, as all nitrogen was given before planting, nitrogen was absorbed actively and was exhausted at a fairly early stage of growth.

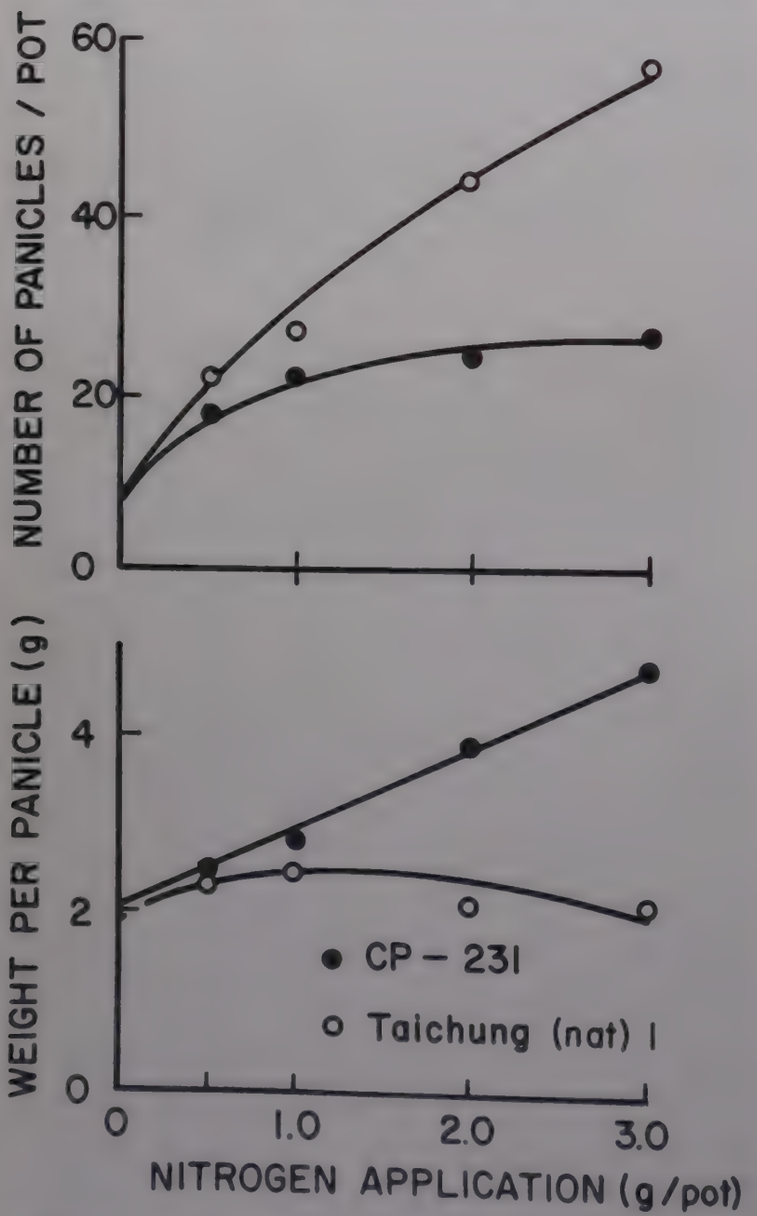


Figure 2.3. Effect of nitrogen application on the panicle number and the weight per panicle of Taichung 1 and CP-231 in a pot test, IRRI, 1962.

The amount of nitrogen absorbed by the plant increased with increases in nitrogen application, but, ignoring the unadapted Japanese varieties, there were no remarkable differences among varieties.

The average absorption percentage was about 70 percent for all except the Japanese varieties. It was greater at the lower nitrogen levels than at the higher levels. There were no important varietal differences in nitrogen absorption in this experiment.

Table 2.9. Percentage of Nitrogen in Panicles, Straw, and Roots and Amount of Nitrogen Absorbed by 13 Varieties Grown at Varying Levels of Nitrogen in a Pot Test, IRRI, 1962.

Variety or N level	Nitrogen content (%) Panicle	Straw	Roots	Nitrogen absorbed (g/pot)	Applied nitrogen absorbed (%)
Averages by variety					
Kinmaze	1.04	0.85	0.51	0.99	61
Norin 25	1.05	0.83	0.62	0.85	52
Fujisaka 5	1.07	0.70	0.60	0.76	46
Norin 8	1.21	0.84	0.70	0.82	51
Tamanishiki	1.14	0.79	0.67	0.75	50
Obanazawa	1.21	0.86	0.53	0.81	59
Chianung 242	0.91	0.49	0.48	1.18	66
Tainan-3	0.92	0.47	0.54	1.33	76
Taichung 1	1.04	0.48	0.36	1.16	67
CP-231	0.95	0.51	0.49	1.28	80
Peta	0.80	0.27	0.34	1.31	75
59-368	0.77	0.27	0.29	1.25	67
Acheh Puteh	0.84	0.26	0.32	1.15	69
Averages by nitrogen level (g/pot)					
0	0.95	0.48	0.49	0.31	—
0.5	0.94	0.46	0.45	0.70	74
1	1.01	0.55	0.46	1.03	70
2	1.04	0.69	0.54	1.43	55
2	1.12	0.76	0.57	1.79	49

Height and Tiller Number

Height increased with increases in nitrogen application up to 2 g/pot (Table 2.10). Maximum tiller number also increased with increases in nitrogen application.

The percentage of effective tillers increased with increases in nitrogen application. This suggests that a shortage of nitrogen during the later stages of growth resulted in the death of some tillers of varieties, such as Peta, 59-368, and Acheh Puteh which were tall and active-tillering.

The length and width of the flag-leaf increased with increases in nitrogen application. There appeared to be no relationship between the degree of nitrogen response under field conditions and the size of the flag-leaf in the pot test.

Summary

In this greenhouse pot test, the varieties which did not respond well to nitrogen under ordinary field conditions responded well when given sufficient light.

Low-response varieties under field conditions had greater total plant weight, higher proportions of straw and root weight to total weight, and lower proportions of panicle weight to total plant weight in this pot test as well as in the field.

Generally speaking, increases in grain yield resulting from greater nitrogen applications are due to increases in panicle number per plant. The increase in the weight per panicle contributes only to a limited extent. However, the panicle weight type (e.g., CP 231) responds to nitrogen by increasing the weight per panicle.

Varieties which tiller vigorously and are tall have small percentages of effective tillers at harvest and inefficiently utilize nitrogen in grain production.

There was no relationship between the degree of nitrogen response and the length or width of the flag-leaf in the pot test.

Under the conditions of this experiment, at least at the later stages of growth, all plants, even at the highest nitrogen level, were fairly deficient in nitrogen. This limited the amount of information that could be gathered.

Table 2.10. Height, Maximum Tiller Number, Effective Tiller Percentage, and Size of Flag-leaf of 13 Varieties Grown at Varying Levels of Nitrogen in a Pot Test, IRRI, 1962.

Variety or N level	Height (cm)	Maximum tiller number per pot	Effective tillers (%)	Size of flag-leaf	
				Length (cm)	Width (cm)
Averages by variety					
Kinmaze	108	42	82	25	1.50
Norin 25	113	33	91	42	1.50
Fujisaka 5	118	28	88	43	1.46
Norin 8	112	33	90	36	1.42
Tamanishiki	110	29	97	34	1.51
Obanazawa	137	23	90	44	1.53
Chianung 242	151	24	81	48	1.58
Tainan-3	150	28	86	44	1.45
Taichung 1	125	41	73	34	1.82
CP-231	161	21	87	43	1.71
Peta	176	42	69	26	1.78
59-368	191	37	69	38	1.43
Acheh Puteh	185	36	60	37	1.57
Averages by nitrogen level (g/pot)					
0	120	13	70	33	1.43
0.5	138	30	72	37	1.51
1	146	35	82	39	1.57
2	152	38	88	43	1.64
3	151	45	88	43	1.66

Varietal Response to Nitrogen Under Water Culture Conditions (Experiment 3)

The previous pot test in the greenhouse showed that varieties which do not respond well to nitrogen under ordinary field conditions respond well when each plant receives sufficient light. Under the conditions of the previous experiment, however, none of the plants was adequately supplied with nitrogen at the later stages of growth even at the highest nitrogen level. Because of a lack of information on plants grown with sufficient light as well as with excess nitrogen, a water culture experiment was conducted.

Method

Eight varieties were used, including the seven involved in the previous experiments and Taichung 65, a *japonica* from Taiwan.

The seeds were sown September 11, 1962, and four seedlings per pot were transplanted on September 20. The pots accommodated 16 liters of

culture solution containing 10 ppm P as NaH_2PO_4, 40 ppm of K, Ca and Mg in the forms of K_2SO_4, $CaCl_2$ and $MgSO_4$, and 1 ppm of Fe and Mn as $FeCl_3$ and $MnSO_4$. The initial pH of the culture solution was adjusted to 4.8. Four levels of nitrogen, i.e., 0, 20, 80, and 320 ppm as NH_4NO_3, were used. Each treatment was duplicated. The culture solution was renewed once a week until 20 days after flowering, when the nitrogen supply was discontinued.

A long-day treatment (about 15 hours light obtained with illumination in the evening) was given for 40 days from September 20 to October 29 to reduce the differences in growth duration among varieties. The plants then were kept under the natural day length condition.

At the end of the long-day treatment, two plants from each pot were sampled and analyzed.

Results

Panicle, Straw, and Root Weight

From 0 to 80 ppm N, panicle weight increased markedly, but it then decreased slightly (Table 2.11).

The yields of Peta and 59-368 were far greater than those of other varieties. The increase between 0 and 80 ppm N was most distinct in Peta and 59-368; the decrease from 80 to 320 ppm N also was greater than in other varieties. The yield of Taichung 1 decreased slightly from 80 to 320 ppm N. The yields of the other varieties increased slightly from 80 to 320 ppm N (Fig. 2.4).

Table 2.11. Dry Weight at Harvest of Panicles, Straw, and Roots of Eight Varieties Grown at Four Levels of Nitrogen in Culture Solution, IRRI, 1962.

Variety or N level	Weight at harvest (g/pot)			Date of harvest
	Panicle	Straw	Roots	
Averages by variety				
Tamanishiki	71	70	10	December 28
Kinmaze	59	86	9	December 28
Taichung 65	86	94	13	January 3
Chianung 242	94	94	13	January 14
Taichung 1	73	88	15	January 3
CP-231	85	101	25	January 4
Peta	124	169	25	January 14
59-368	133	201	29	January 24
Averages by nitrogen level (ppm)				
0	2	3	1	–
20	102	113	21	–
80	134	163	21	–
320	126	173	21	–

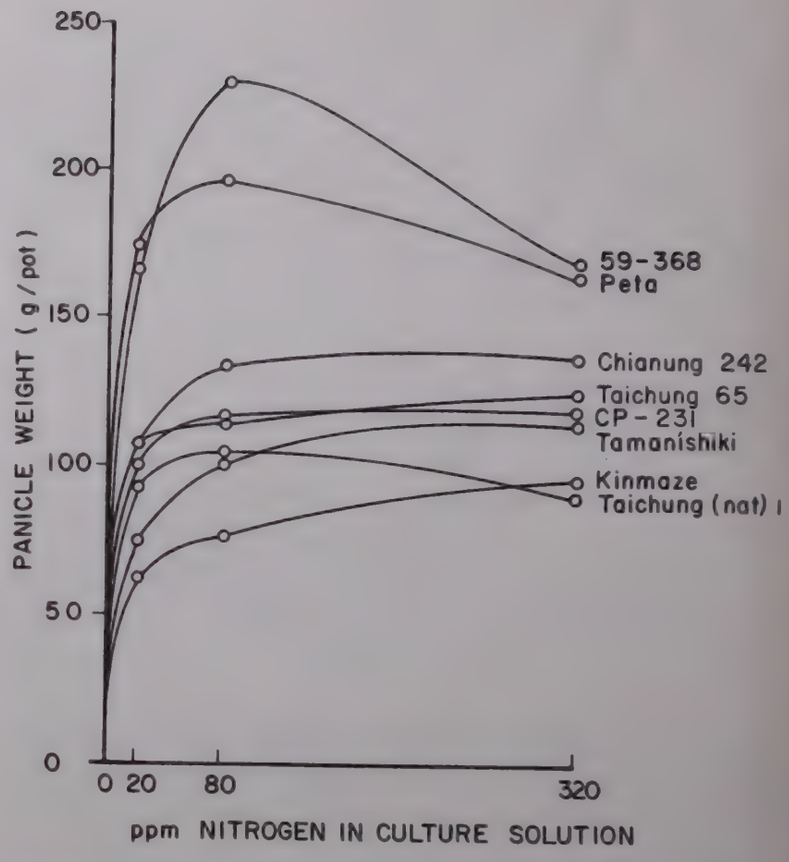


Figure 2.4. Panicle weight of eight varieties grown at four nitrogen levels in culture solution, IRRI, 1962.

Weight of the straw increased with increases in nitrogen up to 320 ppm. The straw weights of Peta and 59-368 were much greater than those of other varieties, and they increased up to 320 ppm N.

Root weight did not vary significantly between 20 to 320 ppm N. The root weights of Peta and 59-368 were far greater than those of other varieties. From 80 to 320 ppm N, the root weights of Peta and 59-368 decreased, whereas those of other varieties either increased slightly or did not vary.

In this experiment, Peta and 59-368 (which gave a negative response to nitrogen under field conditions) produced high grain yields, a large amount of dry matter, and high straw and root weights. However, the panicle and root weights of these varieties decreased when nitrogen was increased from 80 to 320 ppm.

Yield Components

Panicle number increased with nitrogen level (Table 2.12).

Weight per panicle increased with an increase from 0 to 20 ppm N, then decreased. In Peta and 59-368, the weight per panicle decreased remark-

Table 2.12. Yield Component Values of Eight Varieties Grown in Culture Solution at Four Levels of Nitrogen, IRRI, 1962.

Variety or N level	Panicles per pot (no.)	Weight per panicle (g)	Spikelets per panicle	Filled grain (%)	1,000-grain weight (g)
Averages by variety					
Tamanishiki	37	1.92	81	90	23.4
Kinmaze	46	1.28	77	75	19.3
Taichung 65	34	2.58	111	75	24.7
Chianung 242	36	2.61	123	88	23.1
Taichung 1	54	1.35	83	71	20.5
CP-231	22	3.86	186	84	18.3
Peta	51	2.44	147	78	19.0
59-368	46	2.89	105	78	29.0
Averages by nitrogen level (ppm)					
0	2.3	0.43	94	81	23.5
20	40	2.55	146	84	24.0
80	58	2.31	151	78	21.3
320	58	2.00	140	77	20.0

ably from 80 to 320 ppm N, but in other varieties the decrease was negligible, or there was a slight increase.

The number of spikelets per panicle also increased with the increase in nitrogen to 20 ppm; there was no significant change between 20 and 320 ppm N. In Peta and 59-368, there was a marked decrease with an increase in nitrogen from 20 to 320 ppm.

The percentage of filled grain was highest at 20 ppm N. There were no substantial varietal differences or interactions between varieties and nitrogen levels.

The unfilled grains were separated further into under-developed and sterile grains by NaCl solution with a specific gravity of 1.06. The majority was sterile. The percentage of filled grain, therefore, is determined largely by the percentage of fertilization.

The 1,000-grain weight was largest at 20 ppm N. There appeared to be no variety x nitrogen level interaction.

With an increase in nitrogen level, the panicle number increased, the number of spikelets decreased or increased, and the percentage of filled grain and the 1,000-grain weight decreased. The differential varietal response in grain weight to high levels of nitrogen is a result of changes in the various yield components and cannot be attributed to a particular component. The number of spikelets per panicle seemed to be most affected by the variety x nitrogen interaction.

Height and Tiller Number

Height at harvest increased with increases in nitrogen level up to 80 ppm N (Table 2.13). Peta and 59-368 were taller than the other varieties.

At 20 ppm N, root length was maximum; at higher levels root growth was markedly reduced. The decrease in the root length of Peta and 59-368 was larger than in other varieties. With the exception of the short roots of Taichung 1, varietal differences in root length were not important.

The maximum tiller number increased with increases in nitrogen level. In Peta and 59-368, the tiller number was already maximum at 20 ppm N; in other varieties, the maximum tiller number was observed at higher levels. The maximum tiller number of Peta and 59-368 was about 80 per pot at the highest nitrogen level. Serious mutual shading within the plant apparently prevented further tiller formation.

Size of Leaves

The length of any particular leaf increased as nitrogen was increased, but there was only a slight change from 20 to 320 ppm N (Table 2.14). The flag-leaves of CP-231 and Chianung 242 were longer than those of other varieties; Peta had short flag-leaves.

The longest leaf on the main stem generally is the third or the fourth from the flag-leaf. How-

Table 2.13. Height and Root Length at Harvest, Maximum Tiller Number, and Percentage of Effective Tillers of Eight Varieties Grown in Culture Solution at Four Levels of Nitrogen, IRRI, 1962.

Variety or N level	Plant height (cm)	Root length (cm)	Maximum tiller number per pot	Effective tillers (%)
Averages by variety				
Tamanishiki	98	38	42	83
Kinmaze	90	37	61	69
Taichung 65	118	41	40	80
Chianung 242	124	45	42	85
Taichung 1	95	28	60	87
CP-231	133	41	24	96
Peta	141	42	66	74
59-368	162	43	58	73
Averages by nitrogen level (ppm)				
0	65	43	4	64
20	134	50	52	81
80	142	34	68	90
320	140	28	72	90

Table 2.14. Length and Width of Leaf Blade on the Main Stem and the Estimated Total Leaf Area of Eight Varieties Grown in Culture Solution at Four Nitrogen Levels, IRRI, 1962.

Leaf position[a]	Variety								N-Level (ppm)			
	Tamanishiki	Kinmaze	Taic. 65	Cha. 242	Taic. 1	CP-231	Peta	59-368	0	20	80	320
Length of leaf-blade (cm)												
1	25	25	33	38	27	41	26	34	17	34	36	36
2	38	35	44	46	39	51	44	57	26	50	49	51
3	58[b]	49	60	59	50	60	55	70	33	64	68	65
4	57	50	64	70	52	69	64	70	33	70	72	69
5	49	44	56	51	49	67	65	73	29	63	69	67
6	46	40	51	47	45	57	59	70	27	57	62	62
7	37	34	48	42	40	51	53	66	25	51	55	54
8	33	28	44	33	34	44	50	63	23	45	48	48
Total	343	305	400	386	336	440	413	503	214	434	458	455
Width of leaf-blade (cm)												
1	1.55	1.50	1.47	1.55	1.73	1.72	1.75	1.60	0.81	1.81	1.91	1.86
2	1.34	1.27	1.37	1.45	1.45	1.37	1.62	1.35	0.73	1.58	1.72	1.67
3	1.24	1.17	1.27	1.32	1.27	1.30	1.45	1.20	0.63	1.45	1.51	1.52
4	1.20	1.15	1.20	1.17	1.17	1.22	1.37	1.12	0.60	1.40	1.44	1.42
Mean	1.33	1.27	1.32	1.39	1.40	1.40	1.54	1.31	0.69	1.56	1.64	1.62
Estimated total leaf area[c]												
	1.32	1.57	1.39	1.49	1.90	1.07	2.80	2.47	0.08	1.75	2.61	2.62

[a] Counted from the flag-leaf.
[b] Longest leaf.
[c] Total length of top four leaves x average width x tiller number x 10^{-4}.

ever, in Peta and 59-368, the fifth or the sixth leaf was the longest. No definite relationship prevailed between nitrogen response and the length of the longest leaf.

The total length of the top eight leaves increased as the nitrogen level was increased to 80 ppm. It then either decreased or increased depending upon the variety. The total leaf length of 59-368 was longest while Kinmaze and Taichung 1 had the lowest total. Generally, the total leaf length of low-nitrogen-response varieties was larger than that of high-response varieties. As there were exceptions, such as CP-231, no distinct relationship emerged between nitrogen response and total leaf length.

The width of any particular leaf increased with nitrogen level. The higher the position, the wider was the leaf. Peta, CP-231, and Taichung 1 had wider leaves than other varieties. No definite relationship was observed between nitrogen response and width of leaf.

To compare the total leaf area of plants, the following product was calculated: total length of the top four leaves x average leaf width x tiller number. Peta and 59-368 had the largest values. This indicates that the nitrogen response character is closely related to total leaf area. Total leaf area varies with tiller number, leaf length and leaf width. No single factor was responsible for changes in total leaf area.

Nitrogen Percentage

During the vegetative stage, dry weight increased with nitrogen level to 80 ppm, then decreased (Table 2.15). The dry weights of Taichung 1, Peta, and 59-368 were far greater than those of other varieties, while that of CP-231 was lowest.

With increases in nitrogen level, the total nitrogen percentage and the proportion of soluble to total nitrogen increased.

The nitrogen percentage of active-tillering varieties, such as Taichung 1, Peta, and 59-368, was

Table 2.15. Dry Weight and Nitrogen Content at the Vegetative Stage and at Harvest of Eight Varieties Grown at Four Nitrogen Levels in Culture Solution, IRRI, 1962.

Variety or N level	At vegetative stage (straw)			At harvest (% N)		
	Dry weight (g/plant)	N (%)	Soluble N / Total N	Panicle	Straw	Roots
Averages by variety						
Tamanishiki	4.4	2.22	0.31	1.26	0.84	1.17
Kinmaze	5.0	1.98	0.31	1.16	1.06	1.32
Taichung 65	5.2	2.24	0.31	1.15	0.98	1.34
Chianung 242	4.5	2.14	0.31	1.45	1.03	1.17
Taichung 1	7.8	2.39	0.36	1.46	1.33	1.42
CP-231	3.0	1.89	0.28	1.19	0.97	1.28
Peta	7.5	2.35	0.34	1.44	1.29	1.36
59-368	7.9	2.36	0.30	1.25	1.20	1.01
Averages by N-level (ppm)						
0	1.1	0.84	0.24	0.83	0.50	0.85
20	6.9	2.28	0.32	1.20	0.59	0.90
80	7.7	2.72	0.34	1.46	1.32	1.52
320	6.2	2.90	0.36	1.68	1.92	1.76

higher than that of other varieties, while the nitrogen percentage of CP-231 was lowest. There were no marked varietal differences in the soluble-total nitrogen ratio.

The nitrogen uptake of low-nitrogen-response varieties (Peta and 59-368) was active at the early stages of growth. The absorbed nitrogen was converted into protein as efficiently as in high-response varieties, resulting in active tillering.

The nitrogen percentage of panicles, straw, and roots at harvest increased with nitrogen level. The change was most noticeable in the straw.

Varietal differences in nitrogen percentage of the straw at low nitrogen levels were small, but were great at high levels. At a high nitrogen level, the nitrogen percentage of Peta, 59-368, and Taichung 1 was higher than in other varieties. The decrease in panicle weight was closely associated with a marked increase of nitrogen in the straw.

Summary

When the nitrogen level was increased from 0 to 80 ppm, there were marked increases in the grain weight of varieties, particularly those low in response to nitrogen in the field. There was a decrease, however, in grain yield of low-response varieties if nitrogen supply was further increased. Yield of varieties which exhibited high response in the field remained about constant as the nitrogen level was increased from 80 to 320 ppm.

Low-nitrogen-response varieties have a greater capacity to absorb and metabolize nitrogen than high-response varieties. However, at extremely high nitrogen levels excessive nitrogen uptake causes an imbalance between nitrogen uptake and assimilation.

Grain yields of different varieties may increase or decrease as nitrogen is increased. This results from an increase in the panicle number, an increase or decrease in spikelet number, and a decrease in percentage of filled grain and 1,000-grain weight. The interaction between variety and nitrogen level is reflected most in the number of spikelets per panicle.

Although size of the flag-leaf on the main stem has no definite relation to nitrogen response, it seems to be related to total leaf area. No definite relationship exists between total leaf area and any single leaf character.

Effect of Light Intensity on Nitrogen Response (Experiment 4)

Results of previous experiments indicated that varieties differ in nitrogen response under ordinary field conditions, but that the varietal differences are eliminated in pot or water culture tests in which each plant has sufficient light.

Nitrogen metabolism is closely related to carbohydrate metabolism. A balance between the amount of nitrogen available to a plant and the photosynthetic activity of the plant is important in maintaining normal metabolism. Consequently, an interaction between intensity of light falling on plants and their response to nitrogen is possible. This experiment was designed to determine if such an interaction exists.

Method

Peta was used in a pot experiment, using a method similar to that of Experiment 2. Three levels of nitrogen, 0, 1, and 3 g per pot, were used.

One set of plants, including the three nitrogen levels, were placed in natural sunlight. Other sets were placed under light intensities of aboot 50 and 25 percent of natural sunlight throughout the growth period. Shading was provided by single and double sinamay screens. There were two replications.

The experiment was conducted from December, 1962, to March, 1963.

Results

Panicle, Straw, and Root Weight

Total dry weight increased greatly with increases in nitrogen level under natural conditions (Table 2.16). With 50 percent light intensity, the increase in dry weight with increases in nitrogen level was not so marked. With 25 percent of the normal light intensity, increasing nitrogen from 1 to 3 g/pot resulted in a decrease in dry weight. Light intensity had little effect when no nitrogen was added, but there were great effects when 3 g/pot N were added.

The same tendency prevailed for the panicle and root weight (Fig. 2.5); however, the adverse effect of reduced light intensity was more pronounced on panicle and, in particular, on root weight.

These data clearly demonstrate an interaction between light intensity and nitrogen response: *The greater the light intensity, the higher the nitrogen response.*

Nitrogen Percentage

The nitrogen percentage of the straw at harvest (Table 2.16) decreased with higher light intensity, especially at high nitrogen levels. The nitrogen percentage of the straw at 3 g/pot and 50 percent light intensity and at 1 and 3 g/pot N at 25 percent light intensity was significantly higher than for other treatments; this indicated an imbalance between nitrogen and photosynthesis.

Next, young plants grown in a standard culture solution were placed under graded light intensity for 10 days. During the 10-day light treatment, dry weight, and especially root weight, decreased as light intensity decreased. Starch percentage decreased remarkably and nitrogen percentage decreased slightly (Table 2.17). These data indicate that as light intensity is reduced, photosynthesis becomes weaker and dry weight decreases. Accumulated starch is used up, root development is retarded, the roots become weaker, thus diminishing nitrogen uptake. Because of the slow nitrogen uptake by shaded plants in pots with the high nitrogen level, much nitrogen is left for growth at later stages. This accounts for the extremely high nitrogen percentage at late stages.

Table 2.16. Dry Weight and Nitrogen Content of the Panicle, Straw, and Roots of the Variety Peta at Harvest under Different Light Intensities and Nitrogen Levels in a Pot Test, IRRI, 1962.

Light intensity (%)	100			50			25		
N-level (g/pot)	0	1	3	0	1	3	0	1	3
Dry weight in grams per pot									
Panicle	11	90	194	8	66	60	8	27	20
Straw	15	145	234	7	44	93	8	40	30
Roots	7	49	35	2	6	7	2	6	2
Total	33	284	463	17	116	165	18	73	52
Nitrogen content of straw (%)									
	0.51	0.37	0.39	0.65	0.62	1.66	0.68	1.11	2.13

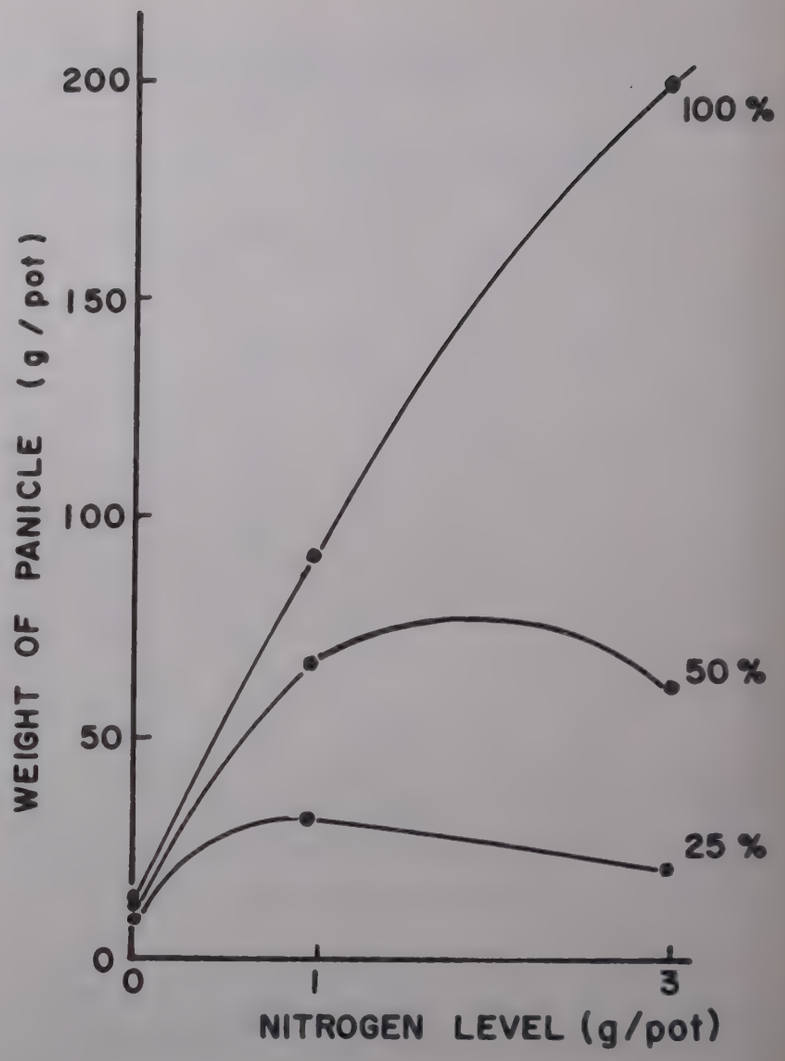


Figure 2.5. Panicle weight of the variety Peta when grown in pot receiving 0, 1, or 3 g N per pot and when plants received 100, 50, or 25 percent of natural sunlight, IRRI, December 1962-March, 1963.

Summary

There is an important interaction between light intensity and nitrogen response. When light intensity is low, the optimum nitrogen level is low.

Table 2.17. Effect of Light Intensity on Dry Weight, Starch and Nitrogen Content of the Variety Peta Grown at 100, 50 and 25 Percent Normal Light Intensity, IRRI, 1962.

Light intensity (%)	100	50	25
Dry weight (g/plant)			
Top	2.19	1.30	0.75
Roots	0.76	0.39	0.16
Starch (%)	10.2	3.2	0.8
Nitrogen (%)	2.75	2.64	2.53

With reduced light intensity, photosynthesis becomes weak, starch accumulation decreases, root development is retarded, and nitrogen uptake slows down. The low photosynthetic rate causes an imbalance between carbohydrate and nitrogen percentage.

Effect of Mutual Shading on Nitrogen Response Under Water Culture (Experiment 5)

Previous experiments indicated that low-nitrogen-response varieties are leafy and that mutual shading among plants in a field population may result from heavy nitrogen applications. To verify this, a water culture experiment was conducted involving an arrangement of pots simulating a plant population in the field. Plants at the border of the artificial "plot" were expected to receive more light than those within the plot. It was intended that, with this arrangement and with graded levels of nitrogen, a mutual shading gradient would be provided.

Method

Seeds of Peta were sown February 12, 1963, four seedlings per pot were transplanted February 22, and other details were similar to those of experiment 3. The plants flowered May 22-27 and were harvested July 1-8. Three nitrogen levels, 5, 20, and 150 ppm, were used. For each level of nitrogen, there were 16 pots arranged as shown in Figure 2.6.

Measurement of light intensity at the base of plants No. 2 and No. 5 were made at different stages of growth. The light intensity was read with a Toshiba illuminometer and was expressed as the percentage of the light intensity at the top of the plants. The value obtained is the "light transmission ratio."

Results

Light Transmission Ratio

The light transmission ratio decreased with the growth of the plants and as the nitrogen level was increased (Fig. 2.6B). The light transmission ratio diminished from the border to the inner portions of the plot. As expected, light intensity varied with nitrogen level and with position in the plot.

Weight of Plant and Panicle

The weight of plant No. 1 increased as the nitrogen level was increased from 5 to 150 ppm (Fig. 2.6C). At any nitrogen level, weight decreased with distance from the border. The decrease was most striking at higher nitrogen levels.

At 5 ppm N, the panicle weight of plant No. 1 was lower than that of No. 2. There was almost no change in the panicle weight of plants No. 2 to No. 5. The panicle weight of No. 1 at 20 ppm N was twice that of No. 1 at 5 ppm N; however, that of No. 5 at 20 ppm N was nearly identical to that at 5 ppm N. These data indicate that in the case of border plants, nitrogen was the limiting factor; however, light was the limiting factor for the inner plants, and an increase in nitrogen level from 5 to 20 ppm did not induce any increase in grain yield.

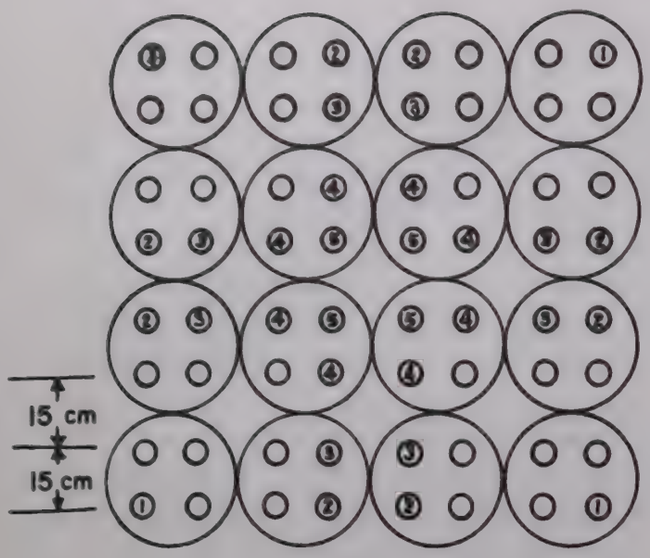
At 150 ppm N, weight was drastically affected by position in the plot, demonstrating that the balance between nitrogen and photosynthesis became progressively worse from position No. 1 to No. 5.

Nitrogen Percentage and Amount Absorbed

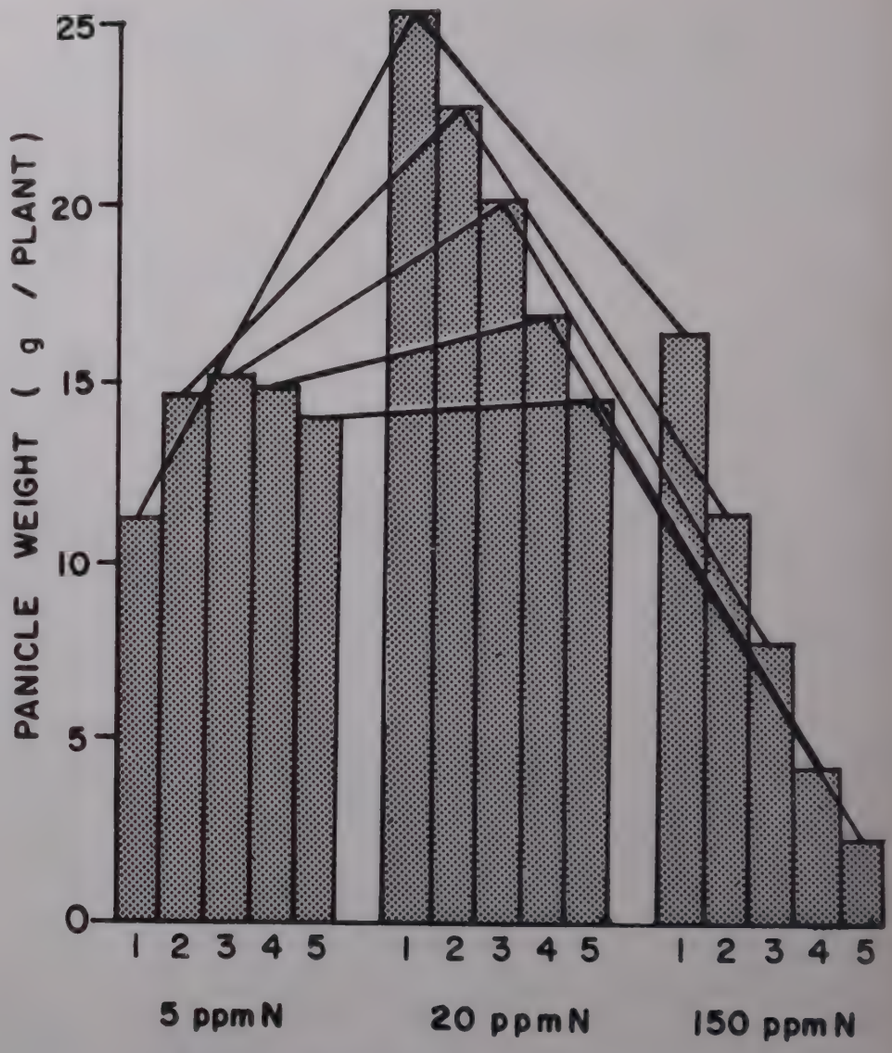
At 5 ppm N, the percentage of nitrogen in active leaf-blades of any plant was about 0.9 and that of the dead leaf-blades was about 0.3 (Fig. 2.7). These plants showed nitrogen deficiency symptoms. At 5 ppm, nitrogen was the major limiting factor at any position in the plot.

At 20 ppm, the percentage of nitrogen in plants No. 1 and No. 2 was about the same as at 5 ppm, signifying that nitrogen still was the limiting factor. The percentage of nitrogen in the active leaf-blades of plants No. 4 and No. 5 was about 1.5 percent showing that nitrogen was not the factor limiting growth.

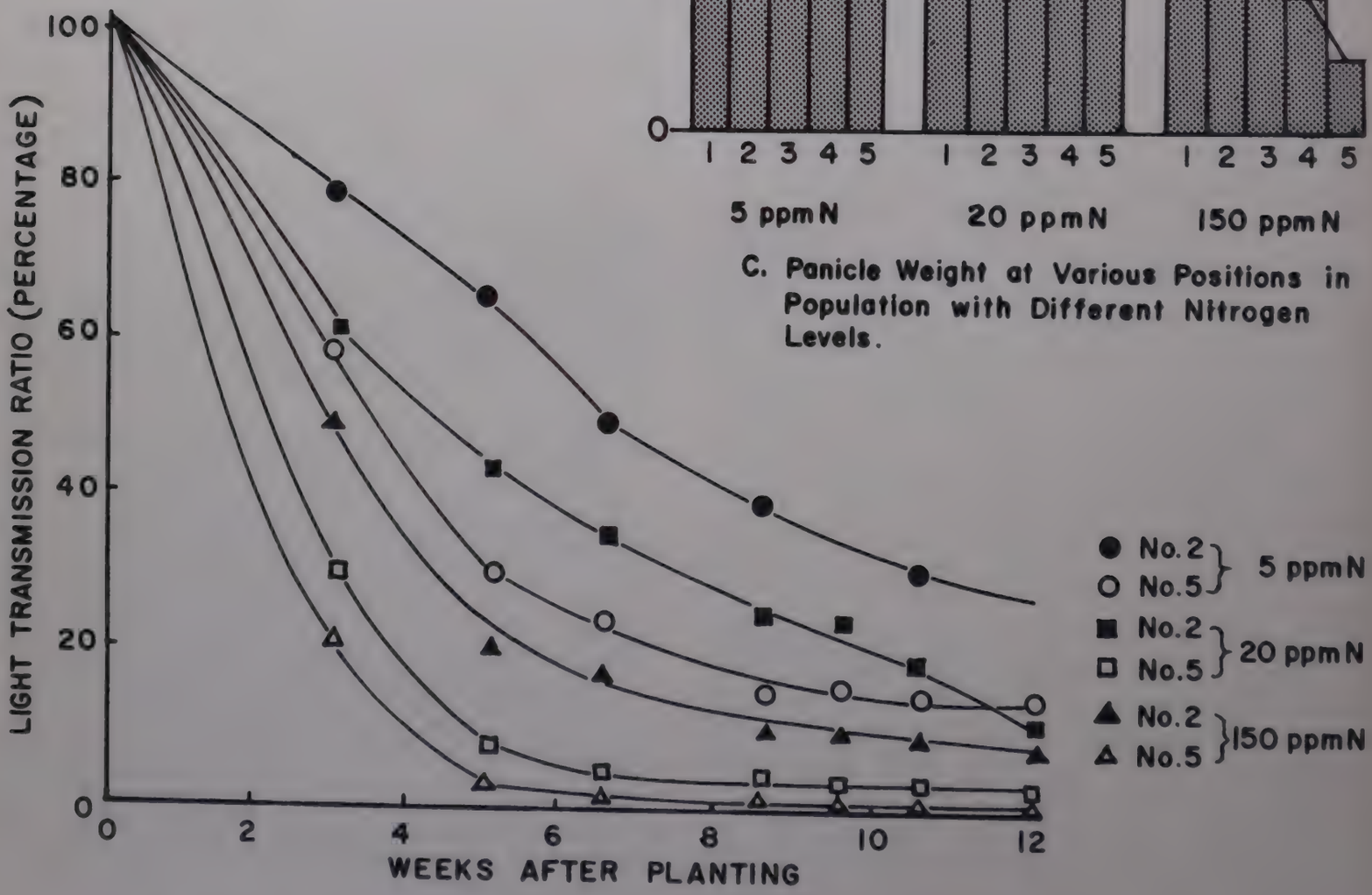
At 150 ppm, the percentage of nitrogen in the active leaf-blades was more than 2.5 percent and that of the dead leaf-blades was more than 1 percent; thus, nitrogen was not limiting growth at any position in the plot.



A. Arrangement of Pots and Plants.



C. Panicle Weight at Various Positions in Population with Different Nitrogen Levels.



B. Light Transmission Rate at Successive Stages of Growth.

Figure 2.6. Layout of the mutual shading experiment (A); data on light transmission ratio (B); and panicle weights (C).

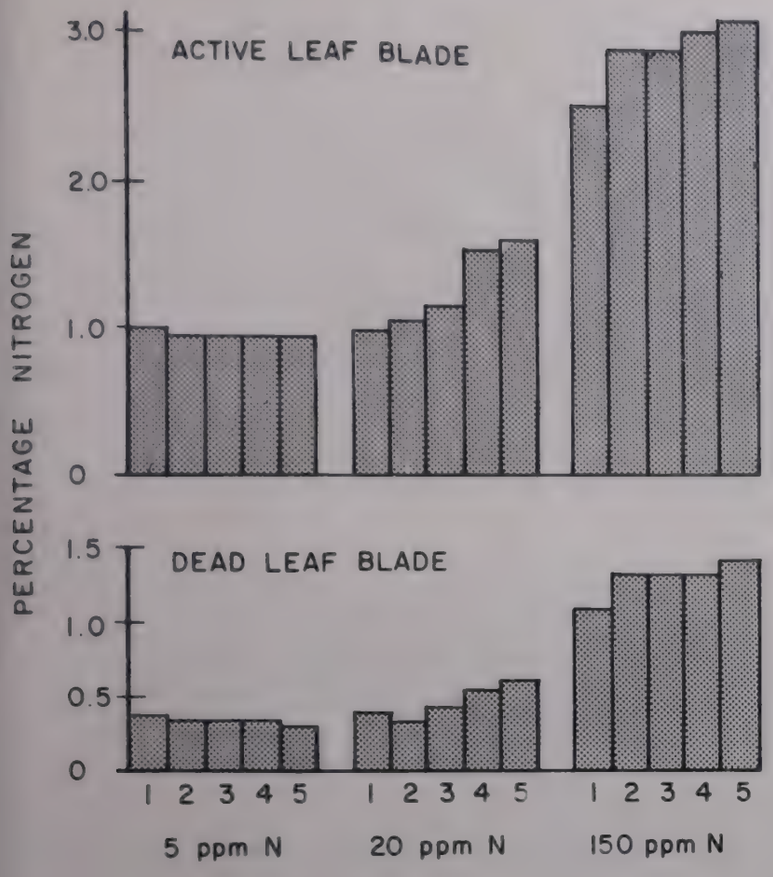


Figure 2.7. Percentage nitrogen at harvest in active and dead leaf blades of Peta at five positions in a plot and when grown at three nitrogen levels, IRRI, February-July, 1963.

All plants suffered from nitrogen shortage at 5 ppm N, and the level of light intensity had little influence on growth. At 20 ppm, nitrogen was limiting for plants situated at the border of the plot. The yield of these plants might have improved had the nitrogen level been increased. On the other hand, even if nitrogen had been added to plants within the plot, it would not have favorably affected the yield. At 150 ppm N, all plants were competing for light, not for nitrogen. The shortage of light was more serious within the plot.

The total nitrogen absorbed by the plant increased with increases in nitrogen level from 5 to 150 ppm. The difference between plants No. 1 and No. 5 was negligible at 5 or 20 ppm N, but was quite large at 150 ppm (Table 2.18).

It is evident that absorption of nitrogen was retarded by mutual shading, even though there was sufficient nitrogen in the solution. Heavy mutual shading caused by the high nitrogen level resulted not only in a decrease in nitrogen uptake but also in a decrease in the efficiency of utilization of absorbed nitrogen.

Morphological Characters of Plants

Height increased as the nitrogen level increased (Fig. 2.8). The border plants were shorter than those inside the plot.

The tiller number of plant No. 1 increased markedly as the nitrogen level was increased from 5 to 150 ppm; the effect decreased with position from No. 1 to No. 5.

The proportion of panicle to total plant weight was large at the low nitrogen level, but it decreased as the nitrogen level was raised. At 5 ppm N, the proportion increased from position No. 1 to No. 5, because the plants near the border were more deficient in nitrogen. At 20 ppm N, the proportion was fairly constant. At 150 ppm N, the proportion decreased strikingly with proximity to the center of the plot.

The proportion of straw to total weight increased with nitrogen level and from position No. 1 to No. 5. Either a nitrogen supply that was not too excessive or an increased light supply favored a high grain-straw ratio.

The proportion of roots decreased with nitrogen level and from position No. 1 to No. 5. The weak root development of the plants inside the high nitrogen level plot was one cause of the low nutrient uptake.

Summary

Yield decreased from the border to the interior plant positions. At the low nitrogen level, the decrease was negligible, but it was serious at the high nitrogen level. This clearly demonstrates that the seriousness of mutual shading increased as the nitrogen level was increased. With a high nitro-

Table 2.18. Percentage of Nitrogen in Plant Parts and Total Nitrogen Absorbed by the Variety Peta in a Culture Solution, IRRI, February-July, 1963.

Plant part	Nitrogen in culture solution (ppm)					
	5		20		150	
	Plant		Plant		Plant	
	1	5	1	5	1	5
Percentage of nitrogen in plant parts						
Panicle	0.64	0.71	1.18	1.27	1.11	1.22
Active leaf blade	0.89	0.89	0.91	1.53	2.51	3.13
Dead leaf blade	0.36	0.29	0.42	0.56	1.20	1.43
Stem + leaf sheath	0.16	0.18	0.25	0.36	1.64	2.34
Roots	0.48	0.55	0.48	0.80	1.62	2.12
Total N absorbed (g/plant)						
Whole plant	0.19	0.18	0.61	0.53	3.85	1.39

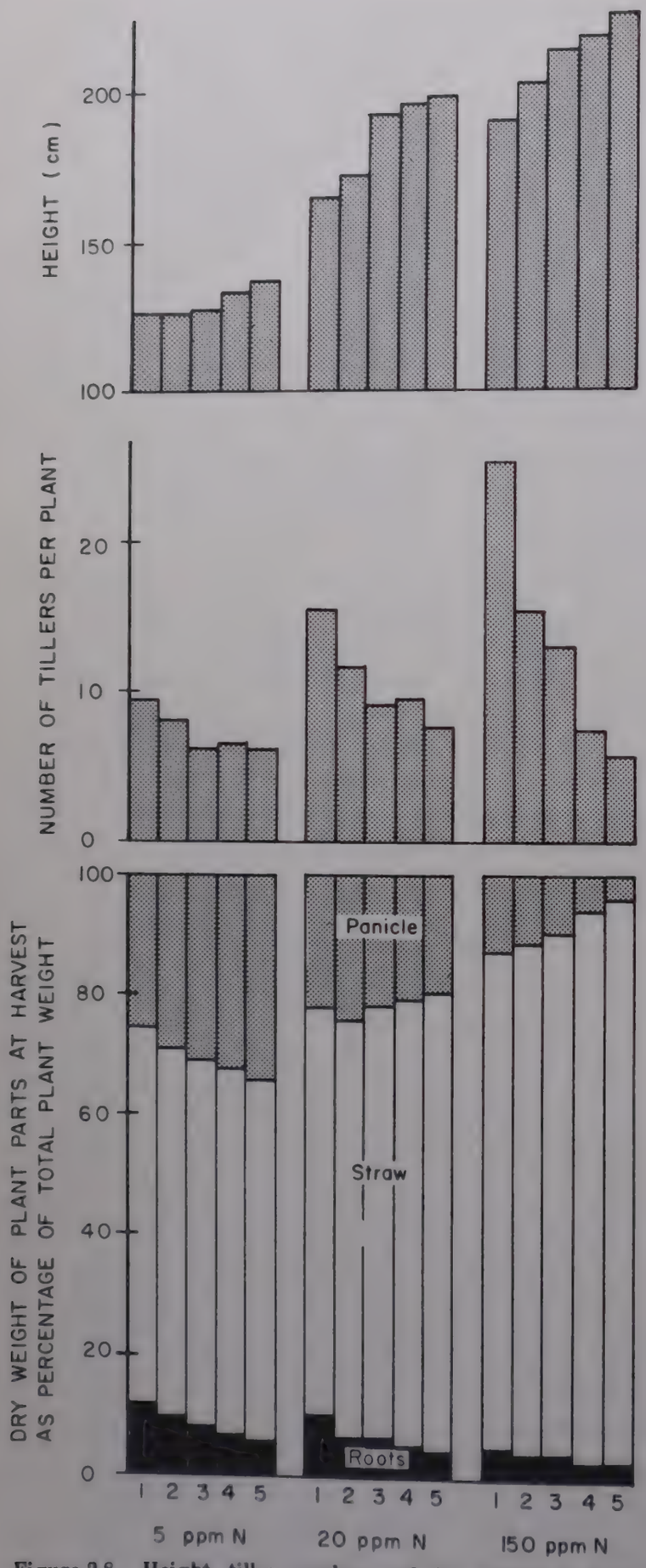


Figure 2.8. Height, tiller number, and dry weight of plant parts at harvest as percentage of total plant weight of the variety Peta when grown at three nitrogen levels and at five positions in a plot, IRRI, February-July, 1963.

gen level and the resulting mutual shading, an imbalance occurred between nitrogen and photosynthesis. Except at the border, the increase in nitrogen level adversely affected the grain yield.

Mutual shading reduced nitrogen uptake by plants at a high nitrogen level. This indicates that even though much nitrogen is added to the soil, nitrogen uptake is not active under serious mutual shading conditions.

With mutual shading, plants grow tall, produce less tillers, have weak roots, and the proportion of grain weight to total plant weight decreases remarkably.

Field Reaction to Nitrogen Application of High- and Low-Nitrogen-Response Varieties (Experiment 6)

In experiment 1, in which no additional nitrogen and 100 kg/ha of nitrogen were used in the field during the rainy season, varieties differed greatly in their response.

To obtain a better understanding of their behavior under field conditions, some of the low- and high-response varieties were again tested.

Method

Seed of the varieties Peta, BPI-76, and Tainan-3 were sown June 5, 1962, and were transplanted June 23 at a spacing of 30 x 30 cm with one plant to a hill. The fields received a uniform application of 17 kg/ha of P and 33 kg/ha of K. Nitrogen at five levels — 0, 30, 60, 90, and 120 kg/ha as ammonium sulfate — was applied just before the final puddling. Each nitrogen level was duplicated in a split plot design, with varieties as the main plots.

The dates of flowering were August 20, September 22, and October 9, and the harvesting dates were October 4, October 22, and November 7 for Tainan-3, Peta, and BPI-76, respectively.

Results

Grain Yield

There were highly significant differences in yield among varieties and the variety x nitrogen level interaction was significant; the differences among nitrogen levels were not significant (Fig. 2.9).

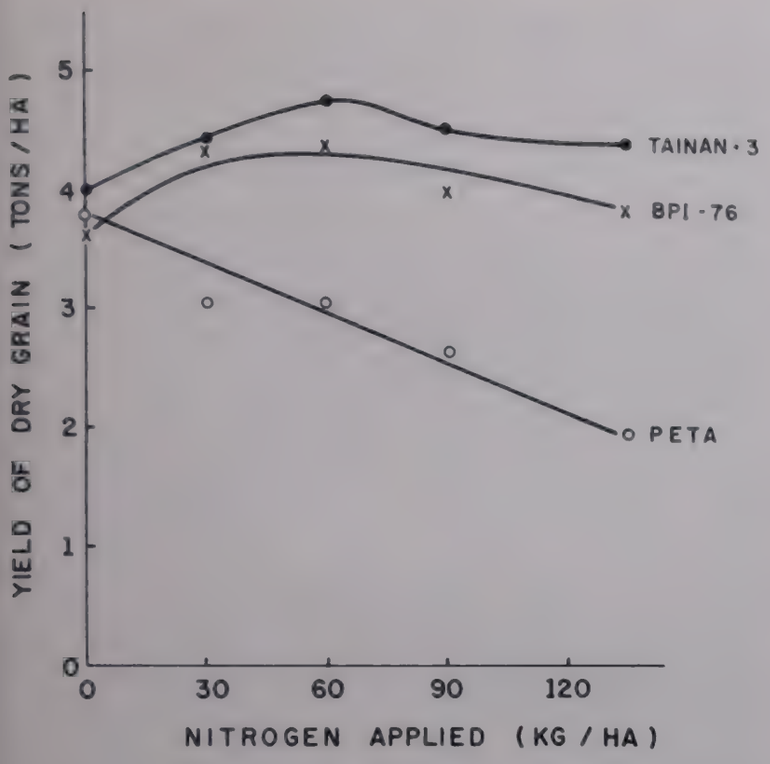


Figure 2.9. Yield of three varieties grown at 5 nitrogen levels, IRRI, 1962 wet season.

Tainan-3 and BPI-76 gave maximum yields at 60 kg/ha N. The maximum yield of Peta was obtained with no added nitrogen. It is apparent that the soil on which this experiment was conducted was fairly high in nitrogen. Nevertheless, there were significant differences among varieties in optimum levels of nitrogen.

Condition of Plants at Harvest

In all varieties, height increased with nitrogen level. Peta was tallest, BPI-76 was shorter, and Tainan-3 was the shortest (Fig. 2.10).

The number of panicles per hill of Tainan-3 and BPI-76 increased with nitrogen level, although the panicle number of the latter was smaller than the other two varieties. The panicle number of Peta was about constant.

In all varieties, the weight per panicle decreased as nitrogen level increased, the reduction being more marked in Peta than in Tainan-3 or BPI-76.

Peta is a tall variety capable of vigorous tillering. In the no-nitrogen plot, lack of space prevented a raise in the nitrogen level from increasing the panicles as the number of panicles per hill was already at its maximum. At the higher nitrogen levels, the Peta plots became more crowded, thus panicle weight decreased as the nitrogen level increased.

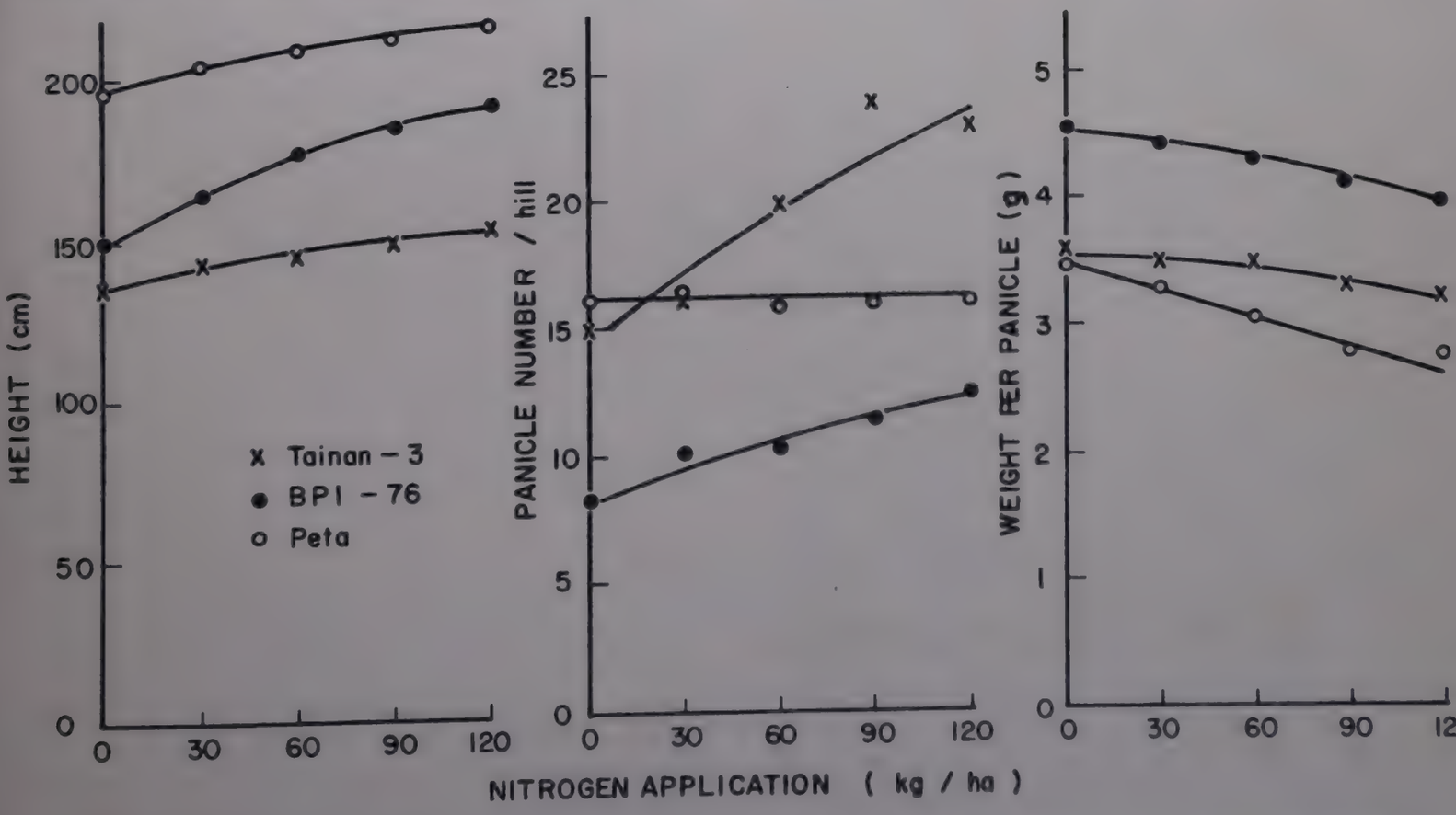


Figure 2.10. Height, panicle number, and weight per panicle of Tainan-3, BPI-76, and PETA grown at three nitrogen levels, IRRI, 1962 wet season. Transplanted at 30 x 30 cm.

Although BPI-76 is also a fairly tall variety, it tillers less. Crowding was not as serious, and the panicle number per hill increased with nitrogen applications up to 120 kg/ha.

With 0 to 60 kg/ha N, no lodging occurred in Tainan-3. With 90 or 120 kg/ha N, the plants started to lodge during the dough stage. Peta lodged completely at all nitrogen levels, and lodging started at flowering. BPI-76 did not lodge with 0 or 30 kg/ha N, but it lodged completely with 60, 90, and 120 kg/ha N; however, the lodging occurred during the dough stage.

There also were differences among varieties in the manner of lodging. In Tainan-3, lodging resulted from the bending of the flexible stem and the heavy panicles, thus causing the panicles to reach the ground. Peta inclined from the base of its stem and fell down completely, probably because of the elongation of the lower internodes and poor root development. The stems of BPI-76 broke at points nearer the base at high nitrogen levels, possibly because of the fragility of the stems.

Growth Processes and Nitrogen Uptake

The tiller number of all varieties in the 0 and 120 kg/ha N plots increased with growth, reached a maximum, and then decreased (Fig. 2.11). The decrease at 120 kg/ha N was more remarkable than with no added nitrogen.

There was almost no decrease in the tiller number of Tainan-3 at 120 kg/ha N, but a slight decrease was noted in the plot without added nitrogen. The tiller number of BPI-76 increased at about the same rate as that of Tainan-3. The maximum number was reached at an early stage of growth and decreased gradually until harvest. In Peta, the tiller number increased quickly, especially at 120 kg/ha N. It then decreased suddenly

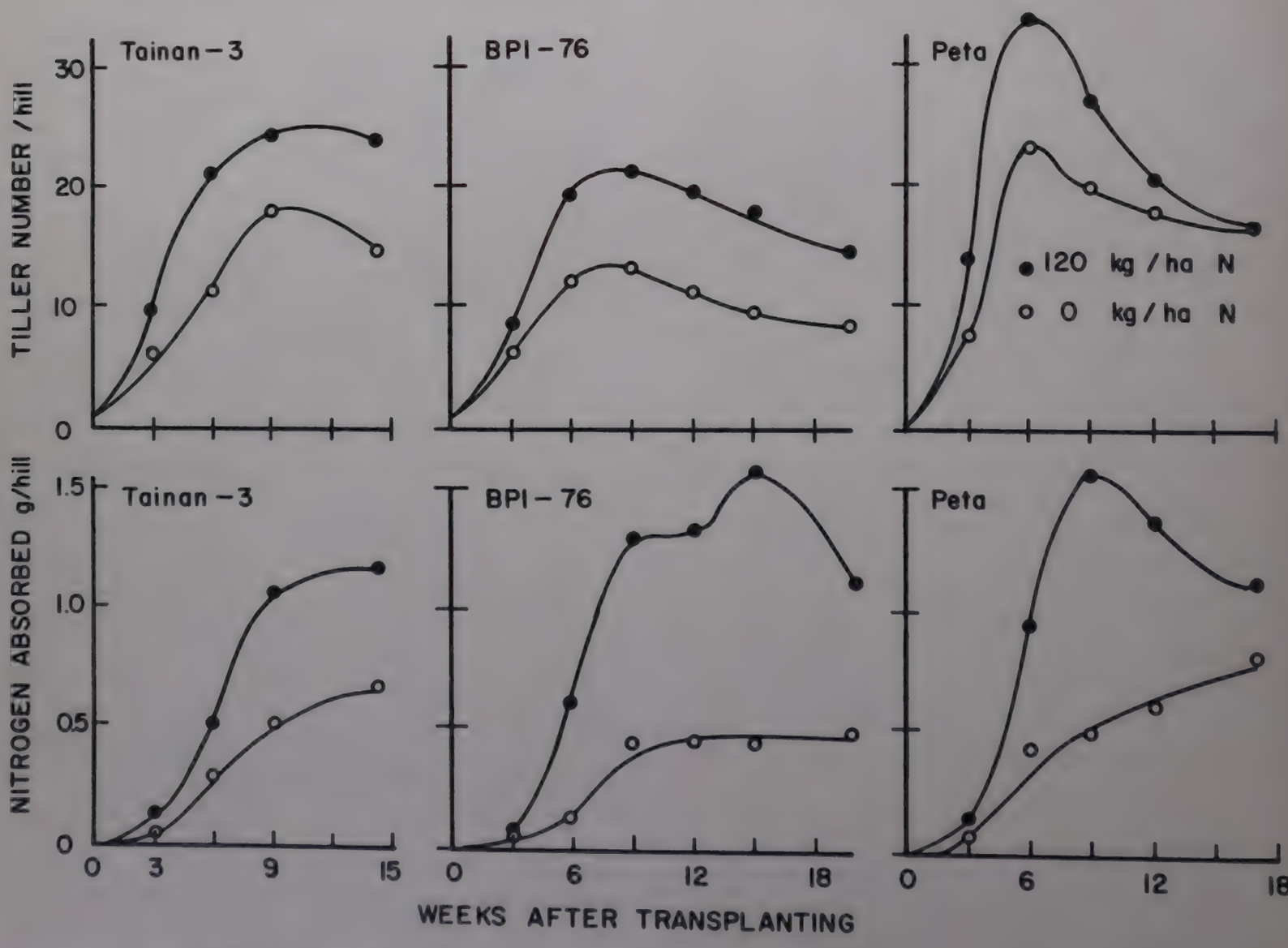


Figure 2.11. Tiller number per hill and grams of nitrogen absorbed per plant at successive growth stages for three varieties grown with 0 or 120 kg/ha added nitrogen, IRRI, 1962 wet season. Transplanted at 30 x 30 cm.

after the maximum tiller number stage. During the early stages of growth, there was a marked difference in the tiller number of Peta at the 0 to 120 kg/ha N level, but the difference then narrowed down because of the rapid death of tillers at the 120 kg/ha N level.

The total nitrogen absorbed increased with growth and was greater at the high nitrogen level. In Tainan-3, nitrogen absorption continued to the end of growth. In the other two varieties, nitrogen uptake continued to the end of growth in the no-nitrogen plot but, at 120 kg/ha N, a maximum amount was reached at the flowering or ear-development stage, after which it diminished.

Summary

During the rainy season, there was a significant variety x nitrogen level interaction: Tainan-3 and BPI-76 gave maximum yields at 60 kg/ha N, whereas the Peta yield was maximum with no additional nitrogen.

In Tainan-3 and BPI-76 the number of panicles per hill increased with nitrogen level; however, there was almost no increase in Peta. Peta produced many tillers, especially at the high nitrogen level; however, the decrease following the maximum tiller number stage was so great that at harvest there was almost no difference between plants grown at the low and high nitrogen levels.

Lodging becomes increasingly serious at higher nitrogen levels. Peta lodged at any level of nitrogen. Tainan-3 and BPI-76 lodged only at high nitrogen levels. Several types of lodging were observed, i.e., bending of the stem, breaking of the stem, and falling over of the entire plant.

In Tainan-3, nitrogen uptake continued to the end of growth at all nitrogen levels. At low nitrogen levels, uptake by Peta and BPI-76 continued to the end of growth but at the high nitrogen level there was a loss of nitrogen from the plants after the booting or flowering stage.

Reaction to Spacing of High- and Low-Nitrogen-Response Varieties (Experiment 7)

Results of experiments 1 and 6 indicated that varieties differ greatly in their response to nitrogen under ordinary field conditions. In experiments 2 and 3 in the greenhouse, varieties exhibiting low response in the field responded well to nitrogen when individual plants received sufficient light. In experiment 4 there was a clear nitrogen response x light penetration interaction.

To measure the interaction between nitrogen response and light penetration under field conditions, the amount of light available to the plants was varied by using different spacings between plants.

Method

Seeds of Tainan-3, Peta, and BPI-76 were sown June 5, and transplanted June 22, 1962, one plant per hill. The field received 40 kg/ha of N, 17 kg/ha of P and 33 kg/ha of K. Six spacings – 10 x 10, 20 x 20, 30 x 30, 40 x 40, 50 x 50, and 60 x 60 cm – were used, each spacing being duplicated in a split plot design, with varieties as the main plots.

Samples and measurements of the light intensity at the base of the plans were taken every 3 weeks until flowering, and at harvest. Tainan-3, Peta, and BPI-76 were harvested on October 4, October 22, and November 7, respectively.

Results

Grain Yield

Differences in grain yield among varieties and among spacings were highly significant, and the variety x spacing interaction was significant (Fig. 2.12).

The optimum spacing for Tainan-3 and BPI-76 was 30 x 30 cm, while for Peta it was 50 x 50 to 60 x 60 cm. It appeared that the optimum spacing for the high-nitrogen-response varieties was closer than for low-response varieties.

Yield Components

As more space was provided, the number of panicles per unit area decreased and the weight per panicle increased (Table 2.19). Since the grain yield per unit area is approximately the product of the number of panicles per unit area and the weight per panicle, there is an optimum spacing for maximum yied for each variety.

The reduction in panicle number per unit area with increases in spacing was more pronounced in Tainan-3 and BPI-76 than in Peta.

The spikelet number per panicle exhibited about the same trend as weight per panicle. There were almost no changes in percentage of filled grain or in 1,000-grain weight with the different spacings.

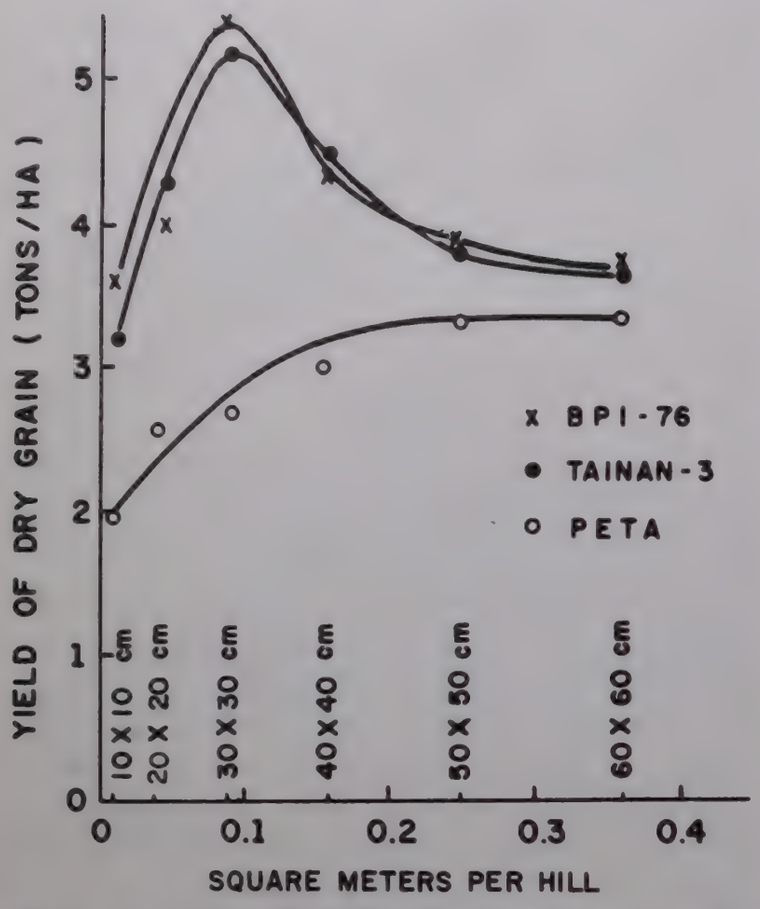


Figure 2.12. Grain yield of Tainan-3, Peta, and BPI-76 at six different spacings, IRRI, 1962 wet season.

Shape of Plants

With increased space, the dry weight of Tainan-3 per square meter decreased, the panicle-straw ratio increased, and the percentage of effective tillers increased (Table 2.20). With Peta, there was little change in dry weight per square meter or in the panicle-straw ratio; however, the panicle-straw ratio was quite low, especially at 10 x 10 cm. The percentage of effective tillers in Peta increased markedly with increase in spacing. When BPI-76 was given increased space, total dry weight per unit area decreased to some extent, but the panicle-straw ratio and the percentage of effective tillers were less affected.

To determine the condition of the plants at different spacings, the dry weight of the leaf blades and of other organs was measured at flowering at 20 cm intervals from the base of the plants (Fig. 2.13). The light intensity at various heights also was measured (Fig. 2.14).

At wider spacings, more of the dry matter was in the lower portions of the plant; this was prominent in Tainan-3, but not so evident in Peta. As the plants had more space in which to grow, the mortality of weak tillers was not significant, and the lower leaves received adequate light and remained alive. Thus, there were more leaves on the lower parts of the plants at wide than at close spacing. In the case of Peta, the field was filled with leaves even at 60 x 60 cm; consequently, there was little difference in the distribution of dry matter at various spacings.

The tiller numbers per hill on August 23, approximately the maximum tillering stage for all varieties, were 45, 69, and 51, for Tainan-3, Peta, and BPI-76, respectively, at the 60 x 60 cm spacing. The tillering capacity of Peta was far greater than that of the other two varieties.

Table 2.19. Yield Component Values of Tainan-3, Peta, and BPI-76 at Different Spacings, IRRI, 1962 Wet Season.

Spacing (cm)	Tainan-3	Peta	BPI-76
Number of panicles per square meter			
10 x 10	312	290	240
20 x 20	237	225	175
30 x 30	208	191	144
40 x 40	175	168	122
50 x 50	152	167	98
60 x 60	139	167	100
Weight per panicle (g)			
10 x 10	1.86	1.53	2.32
20 x 20	2.96	2.34	4.28
30 x 30	3.21	3.12	4.72
40 x 40	3.49	3.43	5.22
50 x 50	3.68	3.39	5.41
60 x 60	3.68	3.32	5.40
Number of spikelets per panicle			
10 x 10	73	112	140
20 x 20	136	151	222
30 x 30	143	150	293
40 x 40	151	156	299
50 x 50	151	142	336
60 x 60	157	162	366
Percentage of filled grain			
10 x 10	87	69	85
20 x 20	74	71	76
30 x 30	78	63	74
40 x 40	83	66	79
50 x 50	82	64	86
60 x 60	72	68	87
1,000-grain weight (g)			
10 x 10	28.0	27.6	21.2
20 x 20	26.5	26.9	21.5
30 x 30	25.8	27.4	21.6
40 x 40	26.0	27.8	21.1
50 x 50	26.0	26.8	21.4
60 x 60	27.0	25.8	21.3

Table 2.20. Total Dry Weight per Unit Area, Panicle-Straw Ratio and Effective Tiller Percentage of Tainan-3, Peta, and BPI-76 at Six Spacings, IRRI, 1962 Wet Season.

Spacing (cm)	Tainan-3	Peta	BPI-76
Total dry weight (kg/sq m)			
10 x 10	1.37	1.54	1.86
20 x 20	1.45	1.65	1.90
30 x 30	1.23	1.77	1.94
40 x 40	1.21	1.66	1.68
50 x 50	0.94	1.62	1.65
60 x 60	0.90	1.63	1.45
Panicle-straw ratio			
10 x 10	0.74	0.40	0.50
20 x 20	0.94	0.47	0.65
30 x 30	1.09	0.51	0.64
40 x 40	1.19	0.53	0.61
50 x 50	1.38	0.51	0.58
60 x 60	1.39	0.57	0.65
Percentage of effective tillers			
10 x 10	53	50	63
20 x 20	76	54	71
30 x 30	85	70	71
40 x 40	87	66	70
50 x 50	100	81	71
60 x 60	100	87	74

There were large varietal differences with respect to lodging. At harvest Tainan-3 had not lodged at any spacing, but at the closer spacings the stems were somewhat bent. Peta lodged completely at harvest at all spacings, but lodged earlier at closer spacings. At spacings of 10 x 10 to 30 x 30 cm, lodging occurred 2 weeks before flowering, and at 40 x 40 to 60 x 60 cm, lodging occurred after flowering. In BPI-76, lodging became increasingly serious with closer spacings and even at 60 x 60 cm, some parts of the plots lodged.

There were more elongated internodes and thinner culms at closer spacings than at wider spacings (Table 2.21).

The mean heights at harvest were 138, 203, and 178 cm for Tainan-3, Peta, and BPI-76, respectively. Peta is a tall variety, susceptible to lodging. Tainan-3 possessed then thinnest culm, but it was most resistant to lodging. The thickness of the culm may not be a critical factor in lodging susceptibility.

Competition for Light and Nitrogen

Figure 2.15 shows the height, tiller number, nitrogen percentage of the straw, and light penetration in Tainan-3 at different stages of growth and at different spacings.

The plants were taller at closer spacings during the early stages of growth, but the maximum height was observed at later stages with the 30 x 30 cm spacing. This disclosed a changing type of competition during growth.

The tiller number per plant vs. spacing curve was almost horizontal on July 13. It was exponential on August 3 and August 24. At harvest (October 4) it was almost a straight line. It is evident that competition set in early at closer spacings. At wider spacings, plants had adequate spacing through the late stages of growth.

The percentage of nitrogen in the straw was lower at closer spacings at all stages of growth. On July 13, however, the differences among spacings were small and the percentage was quite high, even at 10 x 10 cm. Nitrogen at this stage did not limit growth at any spacing. On August 3, nitrogen percentage at 10 x 10 and 20 x 20 cm was significantly lower than at wider spacings, indicating that at this stage of growth nitrogen was the limiting fac-

Table 2.21. Length and Diameter of Internodes of Tainan-3, Peta and BPI-76 at 10 x 10 and 60 x 60 cm, IRRI, 1962 Wet Season.

Node number counted from top	Variety and spacing between hills (cm)					
	Tainan-3		Peta		BPI-76	
	10 x 10	60 x 60	10 x 10	60 x 60	10 x 10	60 x 60
Length of internode (cm)						
Panicle—1	35	44	43	43	37	42
1-2	21	22	26	27	25	33
2-3	15	11	24	24	22	17
3-4	10	7	19	26	18	14
4-5	6	2	20	26	15	13
5-6	2	—	14	17	9	12
6-7	—[a]	—	7	9	5	8
7-8	—	—	4	—	3	4
8-9	—	—	3	—	—	—
Diameter of internode (mm)						
Panicle—1	2	3	2	4	2	4
1-2	3	5	4	6	4	6
2-3	4	6	5	7	4	7
3-4	4	7	5	7	4	7
4-5	5	7	6	8	6	8
5-6	6	—	6	9	6	10
6-7	—	—	6	9	7	11
7-8	—	—	6	—	7	12
8-9	—	—	6	—	—	—

[a] Internodes shorter than 1 cm were not recorded.

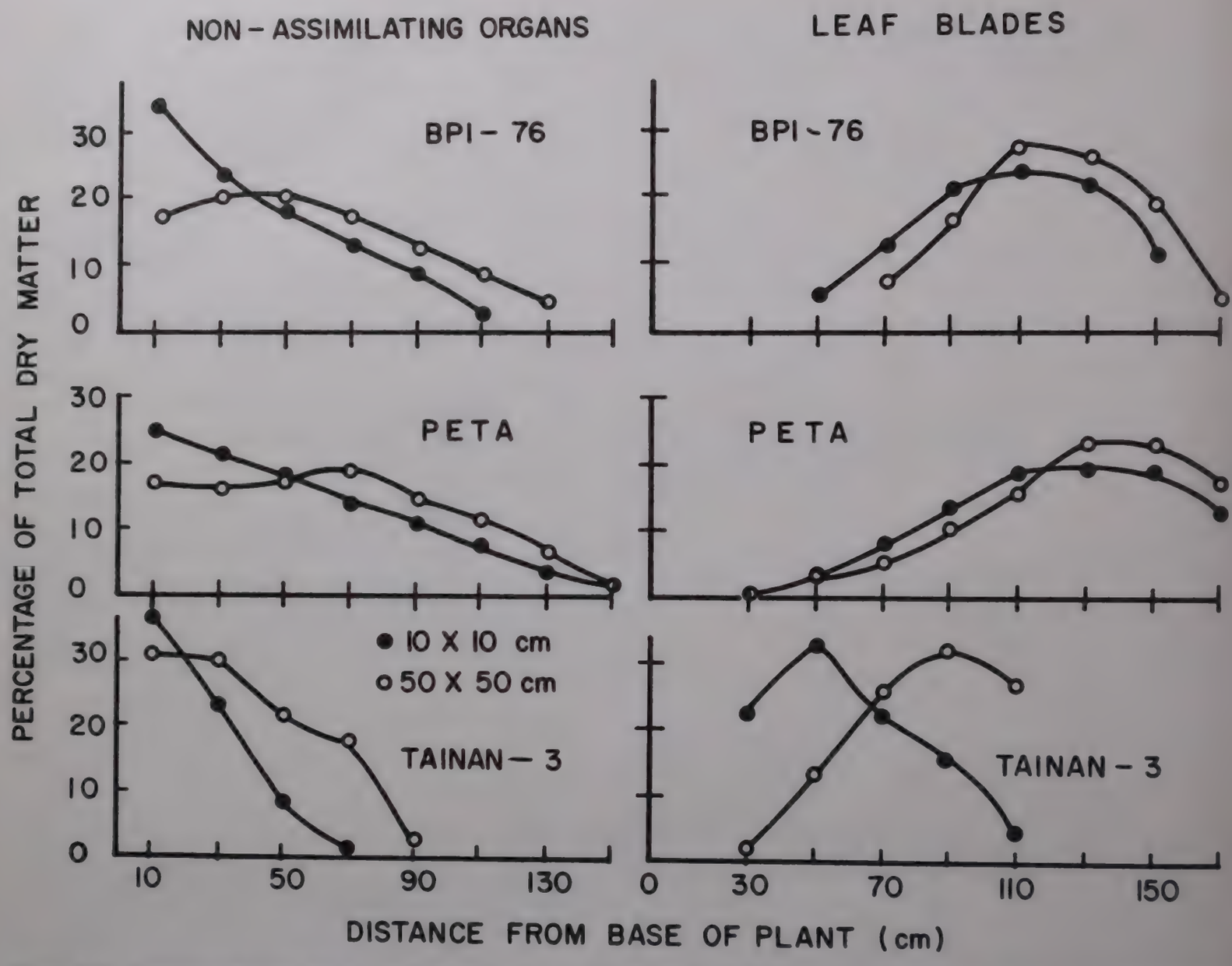


Figure 2.13. Percentage of total dry matter at flowering accounted for by leaf blade or non-assimilating organs at 20-cm intervals from the base of Tainan 3, Peta, and BPI-76, IRRI, 1962 wet season.

tor. On August 24, percentages of nitrogen at spacings between 10 x 10 and 30 x 30 cm were lower than at wider spacings. At harvest (October 4) the nitrogen percentage was slightly higher at wider spacings, but even at 60 x 60 cm, it was only 0.4 percent – this is not high for this stage of growth. Larger plants could be obtained by applying more nitrogen.

The light transmission ratio was lower at closer than at wider spacings. The light transmission ratio-spacing curve was exponential at the early stages of growth but became almost a straight line at later stages of growth. The competition for light was serious from the beginning of growth at 10 x 10 cm but at wider spacings it set in only when the plants were larger.

Under the conditions of this experiment, competition for light occurred first and that for nitrogen followed. This was true for all spacings. For example, on July 13, at 10 x 10 cm, light and not nitrogen was limiting, but on August 3, both nitrogen and light were limiting.

To identify varietal differences in competition among plants, the tiller number per hill, percentage of nitrogen in the straw, and light transmission ratio were measured in all varieties on July 13, August, 3, and at flowering (Fig. 2.16).

On July 13, there were almost no differences in tiller number in any variety, suggesting that no serious competition occurred. By August 3, there were differences at different spacings. In Tainan-3 and BPI-76, increases in tiller number were not prominent at spacings wider than 30 x 30 cm, but

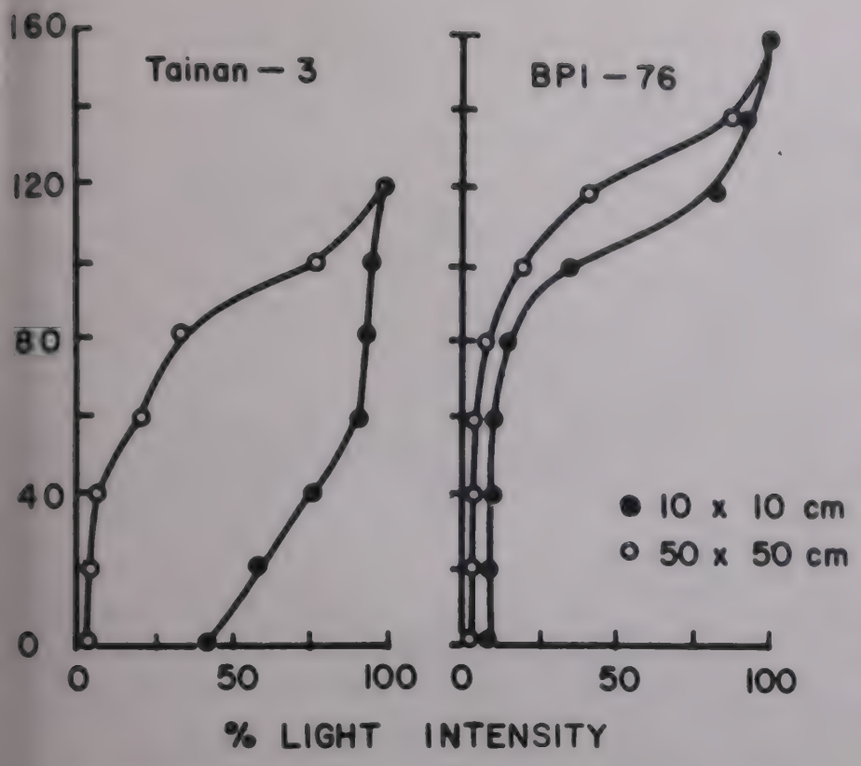


Figure 2.14. Percentage of light reaching points at varying distances from the base of plants of Tainan-3 and BPI-76 spaced 10 x 10 and 50 x 50 cm, IRRI, 1962 wet season.

in Peta the tiller number per hill increased with each increase in spacing. Peta had more tillers than the other varieties at wide spacings. At flowering the tiller number-spacing curve was exponential in Tainan-3 but was linear in Peta and BPI-76. The linear relationship was due to greater competition at wider spacings.

On July 13, at 10 x 10 cm, the light transmission ratio was low in all varieties, but at 20 x 20 cm there were marked differences among varieties. Because Peta is tall and active-tillering, the light transmission ratio in Peta plots was lower than in plots of Tainan-3 or BPI-76. On August 3, there were even greater differences among varieties, probably because of the shading resulting from the excessive vegetative growth of Peta. At the wider spacings, the light transmission ratio at flowering of Tainan-3 was fairly high, and it was low in BPI-76 at any spacing. The low light transmission ratio in BPI-76 results from its long growth duration.

The percentage of nitrogen in the straw of Peta on July 13 was higher than that of Tainan-3 or BPI-76. By August 3, Tainan-3 had a lower nitrogen percentage than the other two varieties; however, there was no indication of varietal differences in competition for nitrogen.

From these data, it can be concluded that the varietal differences in growth habit resulted in differences in the penetration of light into lower layers of foliage; i.e., there were differences in the light transmission ratio. Because of the rapid, early vegetative growth of Peta, competition for light occurred early and was more serious in Peta than in Tainan-3 or BPI-76.

Nitrogen Absorption Process

Peta absorbed nitrogen more actively than the other varieties (Fig. 2.17). At 10 x 10 cm, nitrogen uptake was active for a relatively short period. A maximum was reached about 40 days after transplanting, after which the amount of nitrogen began to decrease. The decrease was most significant in Peta. At 60 x 60 cm, nitrogen was taken up gradually to the end of growth by all varieties.

Summary

When Tainan-3, BPI-76, and Peta were grown at six different spacings during the rainy season, the number of panicles per unit area decreased and the weight per panicle increased with increases in spacing. Because of these opposing effects, there

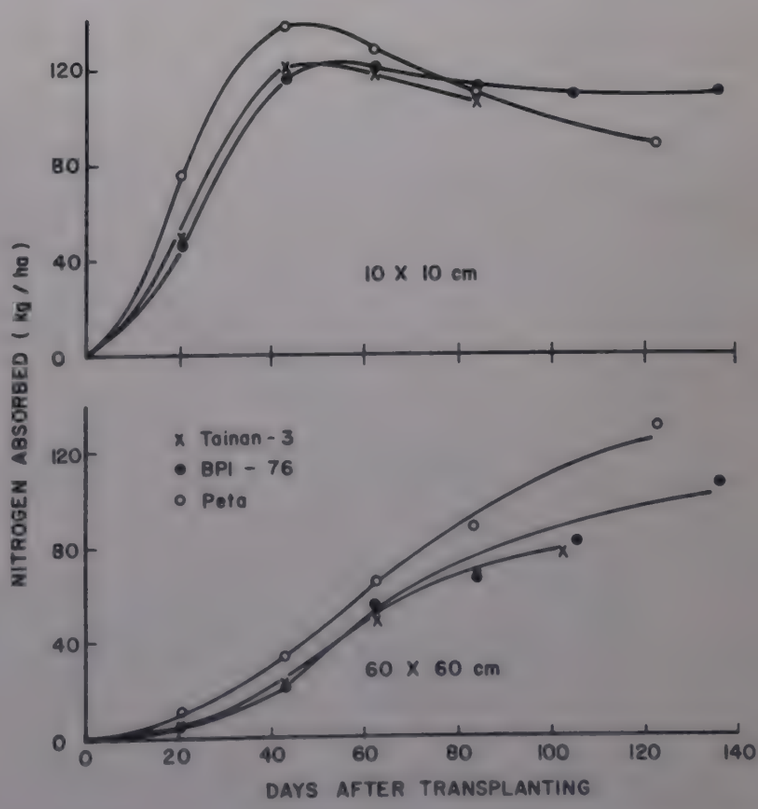


Figure 2.17. Kilograms nitrogen absorbed per hectare by three varieties at two spacings in the field, IRRI, 1962 wet season.

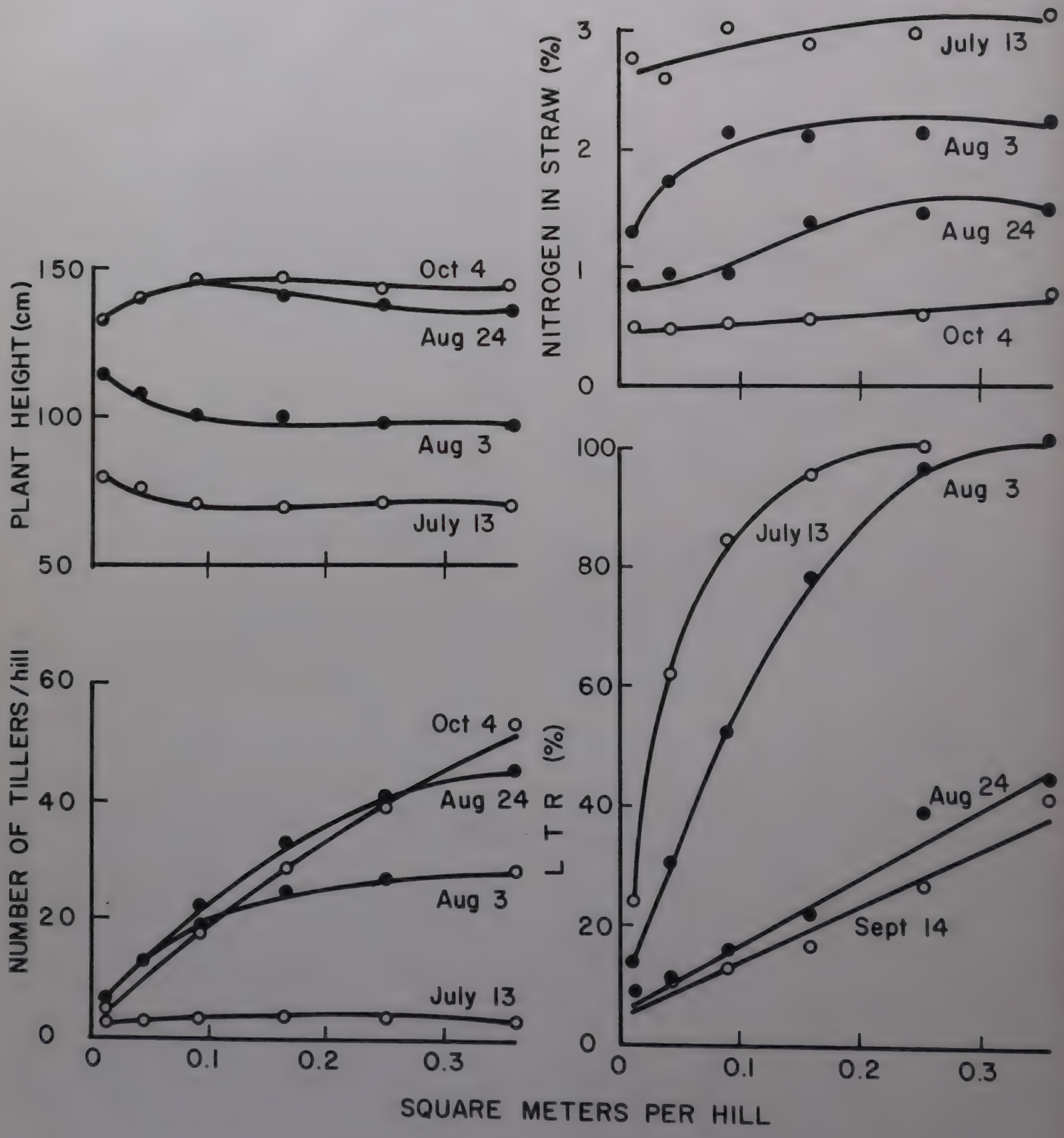


Figure 2.15. Height, tiller number, percentage nitrogen in straw, and light intensity at the base of plants of Tainan-3 at successive stages of growth, IRRI, 1962 wet season.

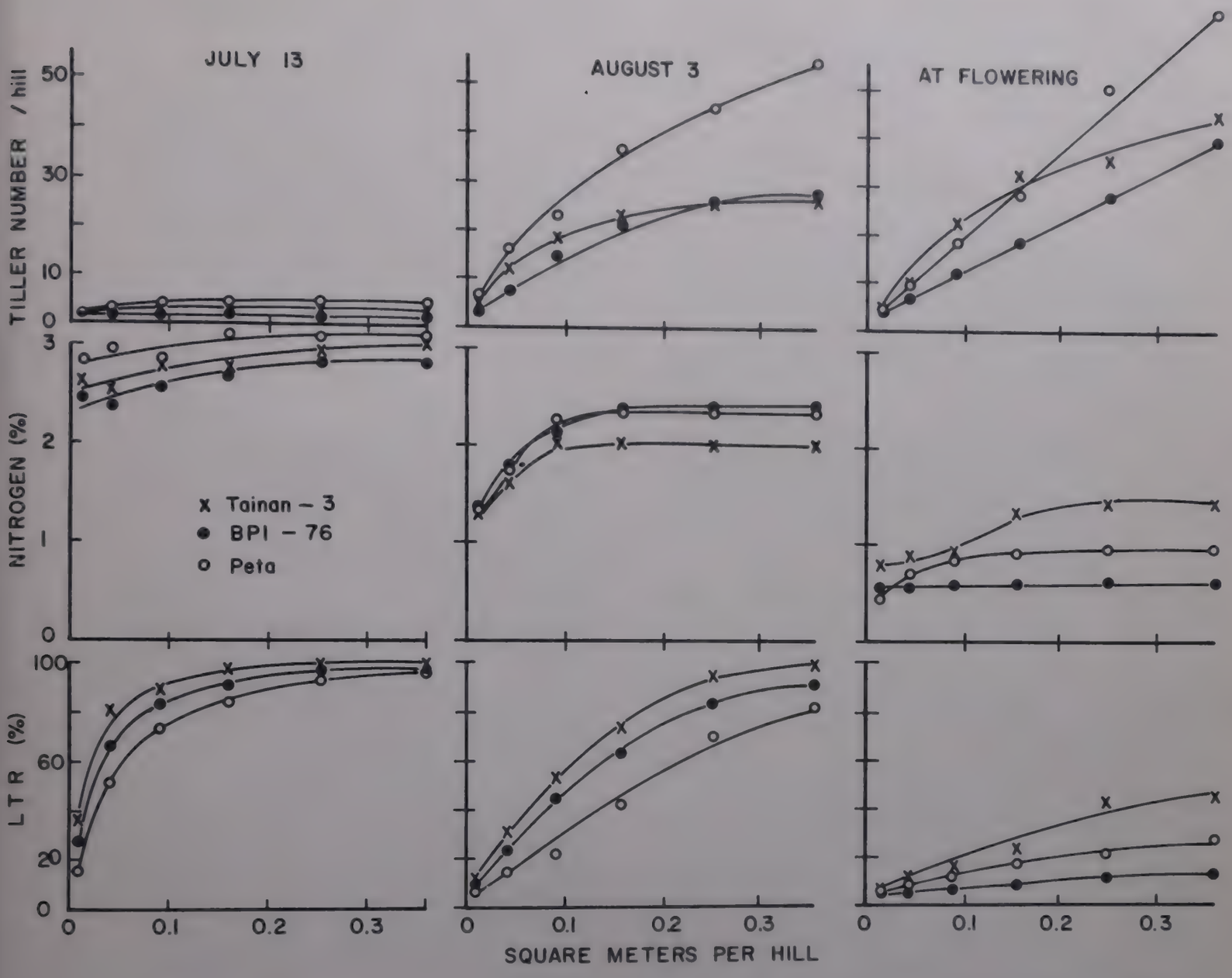


Figure 2.16. Tiller number, percentage nitrogen in straw, and light penetration at various spacings and at successive stages of growth of three varieties, IRRI, 1962 wet season.

was an optimum spacing for each variety. Maximum yield was obtained at 30 x 30 cm with Tainan-3 and BPI-76, and at 50 x 50 cm with Peta. It was concluded that the optimum spacing for a high-nitrogen-response variety is closer than that for a low-response variety.

Plants compete for light and for nitrogen in a field. Competition sets in earlier as spacing becomes closer. Competition for light occurs earlier than for nitrogen, this being more distinct in low-nitrogen-response varieties which are tall and which tiller actively.

The lower internodes are longer and thinner at close than at wide spacings. There also is more dry matter in the upper portions of the plant at closer spacings. These characters result in greater lodging at the closer spacings.

Interactions Among Varieties, Nitrogen Levels, and Spacing (Experiment 8)

Results of experiments 1 and 6 identified varietal differences in nitrogen response, and data from experiment 7 demonstrated that low-nitrogen-response varieties have a wider optimum spacing than high-nitrogen-response varieties.

The results also indicated that there are interactions among varieties, nitrogen levels, and spacing. To acquire information about these interactions, another experiment was conducted during the dry season, 1962-1963.

Method

Century Patna 231, Taichung (Native) 1, and Peta were used. CP-231 and Taichung 1 are high-nitrogen-response varieties; the former is a typical "panicle weight" type and the latter, a typical "panicle number" type. During the wet season, Peta is a low-nitrogen-response variety under field conditions.

Two nitrogen levels – no additional and 100 kg/ha – were basally applied, and three spacings – 15 x 15, 30 x 30 and 60 x 60 cm – were used. Within each treatment, there were subplots planted with one and four plants per hill.

A split-split plot design, with two replications, was used. Nitrogen levels were main plots which were split using plots of varieties running in a perpendicular direction. The spacing subplots were again split to permit testing of the effect of number of plants per hill.

The seeds were sown December 5, 1962, and transplanted December 20. The dates of flowering were March 15 for CP-231 and Taichung 1, and March 21 for Peta. The dates of harvest were April 10 for CP-231 and Taichung 1, and April 20 for Peta.

Samples were taken on January 29 (40 days after transplanting), at flowering, and at harvest. Data were summarized by variety, by nitrogen level, by spacing, and by number of plants per hill.

Results

Grain Yield

Generally speaking, grain yields and nitrogen response were higher in the dry season than in the rainy season (Table 2.22, Table 2.1).

Considering overall averages, the grain yield of Peta was highest, that of Taichung 1 was almost as high, and that of CP-231 was lowest. Yield increased with increases in nitrogen application and with decreases in spacing. Although not significant, one plant per hill outyielded four plants per hill.

There was a highly significant variety x spacing interaction (Fig. 2.18A). The grain yield of CP-231 decreased markedly with an increase in spacing, while that of Peta was higher at 30 x 30 cm than at 15 x 15 cm. The yield of Taichung 1 at 15 x 15 cm and 30 x 30 cm was almost the same.

Table 2.22. Grain Yield of Three Varieties at Three Spacings, Two Nitrogen Levels, and with One and Four Plants per Hill, IRRI, 1962-63 Dry Season.

Spacing (cm)	Plants per hill	Yield in tons per hectare by variety and N level					
		CP-231		Taichung 1		Peta	
		0 kg/ha	100 kg/ha	0 kg/ha	100 kg/ha	0 kg/ha	100 kg/ha
15 x 15	1	3.99	5.03	6.77	8.23	6.10	7.59
	4	4.37	5.52	6.30	5.79	6.88	6.61
30 x 30	1	3.68	4.84	6.04	7.59	6.32	7.68
	4	3.84	4.68	5.99	7.29	6.52	7.27
60 x 60	1	2.59	3.79	4.78	6.53	5.35	6.73
	4	2.80	4.49	4.91	6.76	5.40	6.84

There was a significant variety x number of plants per hill interaction (Fig. 2.18B). The yield of CP-231 with four plants per hill was higher at all spacings than with one plant. On the other hand, the yield of Taichung 1 at closer spacings was higher with one plant per hill than with four plants. For Peta, there appeared to be some advantage of a single plant per hill at the 15 x 15 cm spacing and high nitrogen level, otherwise no important differences were observed.

The nitrogen x spacing interaction also was significant, the effect of nitrogen being larger at wider spacings (Fig. 2.18C).

Although not statistically significant, there was a tendency towards greater effect of nitrogen with one plant per hill than with four plants (Fig. 2.18D). This largely resulted from the high yields with single plants of Peta and Taichung 1 at 15 x 15 cm, and with 100 kg/ha N (Table 2.22).

The variety x nitrogen x spacing interaction was high significant (Fig. 2.18E). The nitrogen response of CP-231 was almost constant at any spacing, while that of Taichung 1 and Peta was greater at wider than at closer spacings. However, all varieties gave their highest yields at close spacings and at the high nitrogen level.

Yield Components

CP-231 produced few panicles with many spikelets and a low 1,000-grain weight; Taichung 1 had

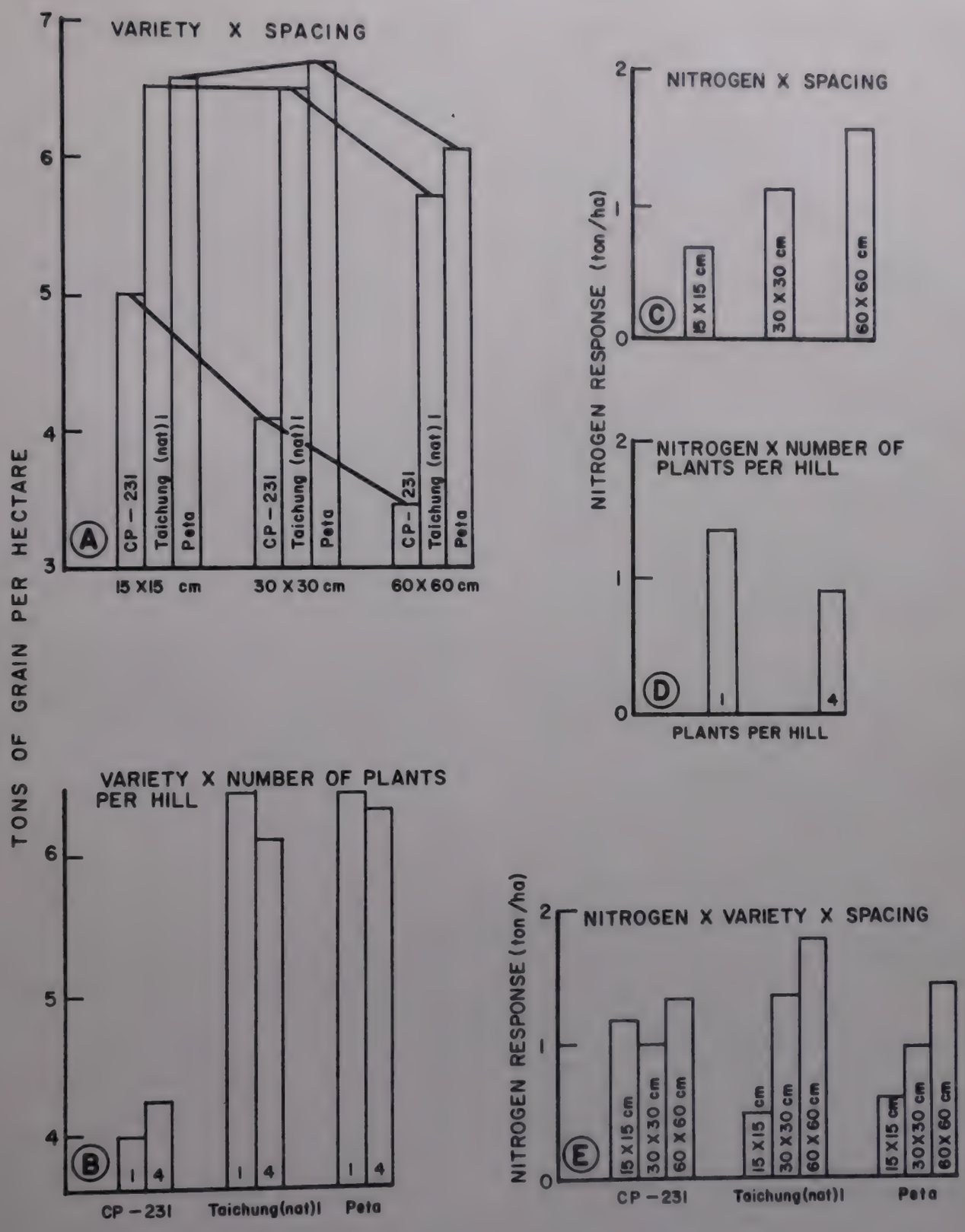


Figure 2.18. Interaction among variety, nitrogen level, spacing, and number of plants per hill, IRRI, 1962-63 dry season.

many panicles with few spikelets and large grains; Peta was intermediate (Table 2.23).

In general, by increasing the nitrogen level, the number of panicles per plant increased but the weight per panicle decreased slightly. The number of panicles per unit field area decreased with increases in spacing; however, the weight per panicle increased because of an increase in the number of spikelets per panicle. The percentage of filled grain as well as the 1,000-grain weight decreased somewhat with increases in spacing. With an increase in number of plants per hill, the panicle number increased but the size of the panicle was reduced.

Table 2.23. Grain Yield and Yield Components of Three Varieties Grown at Three Spacings, Two Nitrogen Levels, and with One and Four Plants per Hill, IRRI, 1962-63 Dry Season.

Characters	Average value by treatment									
	Variety			Nitrogen (kg/ha)		Spacing (cm)			Plants/hill	
	CP-231	Taichung 1	Peta	0	100	15 x 15	30 x 30	60 x 60	1	4
Grain yield (ton/ha)	4.14	6.42	6.61	5.13	6.30	6.10	5.98	5.08	5.76	5.68
Panicle no/sq m	180	337	231	219	284	413	222	163	238	260
Wt/panicle (g)	3.08	2.21	3.51	2.96	2.89	2.32	3.01	3.56	3.07	2.78
No. of spikelets/panicle	169	102	154	142	140	107	138	178	149	133
Percentage of filled grain	84.0	86.9	81.9	85.0	83.6	87.6	85.8	79.6	84.4	84.3
1,000-grain weight (g)	20.5	24.0	24.2	22.0	23.0	23.1	23.0	22.0	22.8	23.0

The ranges in the number of panicles per square meter were 72-267, 193-544, and 142-422 for CP-231, Taichung 1, and Peta, respectively. The greatest change in panicle number was in Taichung 1.

The ranges in the weight per panicle were 1.8-4.1 g, 1.9-2.4 g, and 2.4-4.2 g for CP-231, Taichung 1, and Peta, respectively. The range was greatest in CP-231.

These data indicate that the size of the panicle was subject to less variability than the number of panicles.

Height, Tiller Number, and Dry Weight

The height of plant increased significantly with additional nitrogen (Table 2.24).

The tiller number per unit area was high in Taichung 1 and low in CP-231. The number increased with added nitrogen and with the number of plants per hill. There were more tillers per unit area at close than at wide spacings. Although tiller number per hill increased with added space, the increase was less than proportional to space.

Peta tillered actively at the start, but after reaching the maximum tiller number stage, its tiller number decreased significantly. Tillering in Taichung 1 was equally active at the early stages of growth, and this variety maintained a high tiller number until the end of growth. CP-231 was slow in tillering, but there was almost no decrease in tiller number after the maximum number was reached.

Table 2.24. Height, Tiller Number, and Dry Weight at Different Stages of Growth of Three Varieties Grown at Three Spacings, Two Nitrogen Levels, and with One and Four Plants per Hill, IRRI, 1962-1963 Dry Season.

Sampling date	Average values by treatment									
	Variety			Nitrogen (kg/ha)		Spacing (cm)			Plants/hill	
	CP-231	Taichung 1	Peta	0	100	15 x 15	30 x 30	60 x 60	1	4
Plant height (cm)										
January 29	71	63	66	67	75	67	66	65	65	68
At flowering	121	92	133	108	122	110	118	119	114	117
Tiller number per square meter										
January 29	165	349	317	207	347	495	247	90	270	298
At flowering	191	359	288	220	339	420	248	169	248	311
Effective tillers, %	94	87	74	90	81	76	84	96	87	84
Dry weight in grams per square meter										
January 29	103	169	173	85	211	281	122	42	117	179
At flowering	786	917	1178	697	1223	1300	978	603	921	1000
At harvest	1120	1298	1552	1071	1577	1620	1348	1006	1327	1321
Panicle-straw ratio	0.81	1.30	1.00	1.14	0.94	0.94	1.01	1.17	1.06	1.02

At the high nitrogen level and at close spacing, tillering was active at the early stages of growth; however, the tiller number decreased significantly after the maximum tiller number stage. On the other hand, with no nitrogen or wide spacing, tillering was slower at the start, but the tiller number was maintained until the end of growth. With four plants per hill, more tillers per unit area were produced than with one plant per hill, but the difference was small. There were differences in the percentage of effective tillers; the percentage was smaller at the *high* than at the *low* nitrogen level and also at a *close* than at a *wide* spacing. The combination of these factors tends to produce a low percentage of effective tillers. For example, the percentage of effective tillers in Peta was low at the *close* spacing and the *high* nitrogen level.

Throughout the growth period, Peta had the highest total dry weight per unit field area and CP-231 had the least. With additional nitrogen, dry weight increased. At a close spacing, dry weight per unit field area was greater than at a wide spacing. The dry weight of the four plants per hill plot was greater than that of one plant per hill. These differences were more prominent at the early stages of growth, and the differences became smaller with growth.

The panicle-straw ratio was large in Taichung 1 and relatively small in CP-231. With the high nitrogen level, the ratio was reduced. The ratio was smaller at closer than at wider spacings.

Leaf Area and Leaf Characters

The leaf area index (LAI: leaf area per unit field area) of Taichung 1 was larger than that of CP-231 (Table 2.25). At an early stage of growth, the LAI of Peta was as large as that of Taichung 1, but at flowering it was smaller than that of Taichung 1. The LAI increased with the high nitrogen application, with a reduction in spacing, and with a greater number of plants per hill.

The LAI increased with growth, and the differences among varieties or among treatments generally became smaller with growth.

The LAI is composed of three components, i.e., the number of tillers per unit field area, the number of leaves per tiller, and the average area per leaf.

Taichung 1 had a large number of tillers per unit of field area, but had fewer and smaller active leaves per tiller. CP-231 had large leaves, but the LAI was small because of the limited number of tillers. Peta also had large leaves but it had fewer tillers than Taichung 1, thus its LAI was smaller than that of Taichung 1.

The high nitrogen application increased tiller number as well as average area per leaf; this caused an increase in the LAI. Decreasing the spacing, however, also increased the tiller number per unit area. The number of active leaves per tiller diminished because of the death of the lower leaves, while the average area per leaf remained constant. The net result was that LAI increased as spacing decreased.

These data indicate that the tiller number per unit field area was the major factor controlling LAI.

CP-231 had thicker leaves than the other varieties. The thickness was decreased by the nitrogen application and by a decrease in spacing.

The light transmission ratio (I/Io) was smallest in Peta and greatest in CP-231. The ratio was decreased by the nitrogen application, by a decrease in spacing, and by the increase in the number of plants per hill.

There was a negative logarithmic relationship between I/Io and LAI (Fig. 2.19). However, the extinction coefficient ($K = -\frac{1}{LAI} \log_e \frac{I}{Io}$) was not a constant value. The K of Peta at flowering was larger than that of the other varieties. The value was higher with no nitrogen than with 100 kg/ha N and was higher at 60 x 60 cm than at 15 x 15 cm. It should be noted that, although Taichung 1 had a high LAI, the light transmission rate was high because of the small K. The small K value of Taichung 1 may be related to its relatively small erect leaf character and short plant type.

At flowering, Peta had a higher proportion of dead leaves than the other varieties. The proportion of dead leaves was increased by the high nitrogen level and by closer spacing.

The nitrogen content of the straw was higher in Taichung 1 and CP-231 than in Peta. It was increased by wider spacing or by use of one plant per hill. These differences were more pronounced at early stages of growth.

Leaf Area and Dry Matter Production

A good correlation existed between LAI and dry weight increase per day during the vegetative phase and the reproductive phase (Fig. 2.20). At earlier growth stages, the greater the LAI, the greater was the dry weight increase per day, but there was little association during ripening.

Table 2.25. Leaf Area Index (LAI) and Leaf Characters at Flowering of Three Varieties Grown at Three Spacings, Two Nitrogen Levels, and with One and Four Plants per Hill, IRRI, 1962-63 Dry Season.

Characteristic	Average values by treatment									
	Variety			Nitrogen (kg/ha)		Spacing (cm)			Plants/hill	
	CP-231	Taichung 1	Peta	0	100	15 x 15	30 x 30	60 x 60	1	4
LAI	2.49	4.29	3.19	2.06	4.53	4.21	3.39	2.29	3.10	3.49
Tiller no. per square meter	191	359	288	220	339	420	248	169	248	311
No. leaves/tiller	4.42	3.69	4.24	4.11	4.13	3.72	4.17	4.47	4.08	4.22
Ave. area/leaf (cm^2)	29.6	27.8	29.8	25.5	33.2	27.2	30.7	29.8	29.3	29.3
$\frac{\text{No. dead leaves}}{\text{Total no. leaves}} \times 100$	27	28	35	28	35	39	34	17	28	32
Thickness of leaves (mg/cm^2)	7.32	5.31	6.54	6.68	6.10	6.02	6.35	6.85	6.37	6.43
I/Io x 100	28	12	6	22	9	9	12	25	17	14
K	0.67	0.64	1.02	0.82	0.73	0.74	0.76	0.83	0.79	0.77
N in straw (%)	1.27	1.34	1.04	1.23	1.22	1.02	1.10	1.49	1.29	1.18

At the early stages of growth, the nitrogen content of the leaves was high, and no mutual shading existed. Dry matter production was a function of the leaf area. However, mutual shading at later growth stages resulted in an unfavorable physiological condition of the lower leaves (extreme cases caused death of the lower leaves). There also was a limited supply of light to the lower leaves so that dry matter production was not proportional to the total leaf area.

The grain yield–LAI curve (Fig. 2.21) illustrates the efficiency of the leaves at flowering in producing grain. Between the range LAI = 0 to 4, the smaller the LAI, the greater was the efficiency of the leaves. The curves for Peta and Taichung 1 took a slightly higher position than that of CP-231, indicating that the leaves of Peta and Taichung 1 were more efficient, at least with an LAI below 4. The curve of Peta reached a peak at LAI = 4, after which there was a decline showing that the increase of LAI exhibited negative efficiency. Above LAI = 4, the Taichung 1 curve continued to rise slightly, probably because of the small K value of the variety. The increase between 5 and 7, however, was small, suggesting that the efficiency of the increased leaf area was low. Above LAI = 7, the curve declined.

The above data demonstrate the important relationship between LAI and mutual shading in connection with grain production.

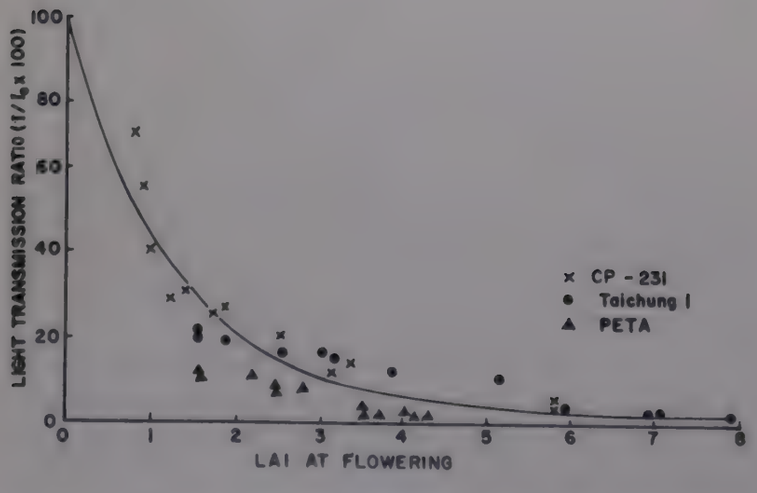


Figure 2.19 Light transmission ratio — leaf area index curve for three varieties, IRRI, 1962-63 dry season.

Summary

Generally speaking, grain yield and nitrogen response were higher in the dry season than in the rainy season.

CP-231 is a variety with medium height, weak tillering capacity, large, thick leaves, and a small extinction coefficient. The weight of the panicle varies greatly. Taichung 1 is a short variety, active in tillering, with small, thin, but erect leaves, and a small extinction coefficient. The panicle size is not affected greatly by environmental conditions. Peta is tall, vigorous in tillering, and its foliage is not easily penetrated by light. It produces only a moderate number of panicles (at harvest) because of a low percentage of effective tillers. The size of the panicle varies considerably with environmental conditions.

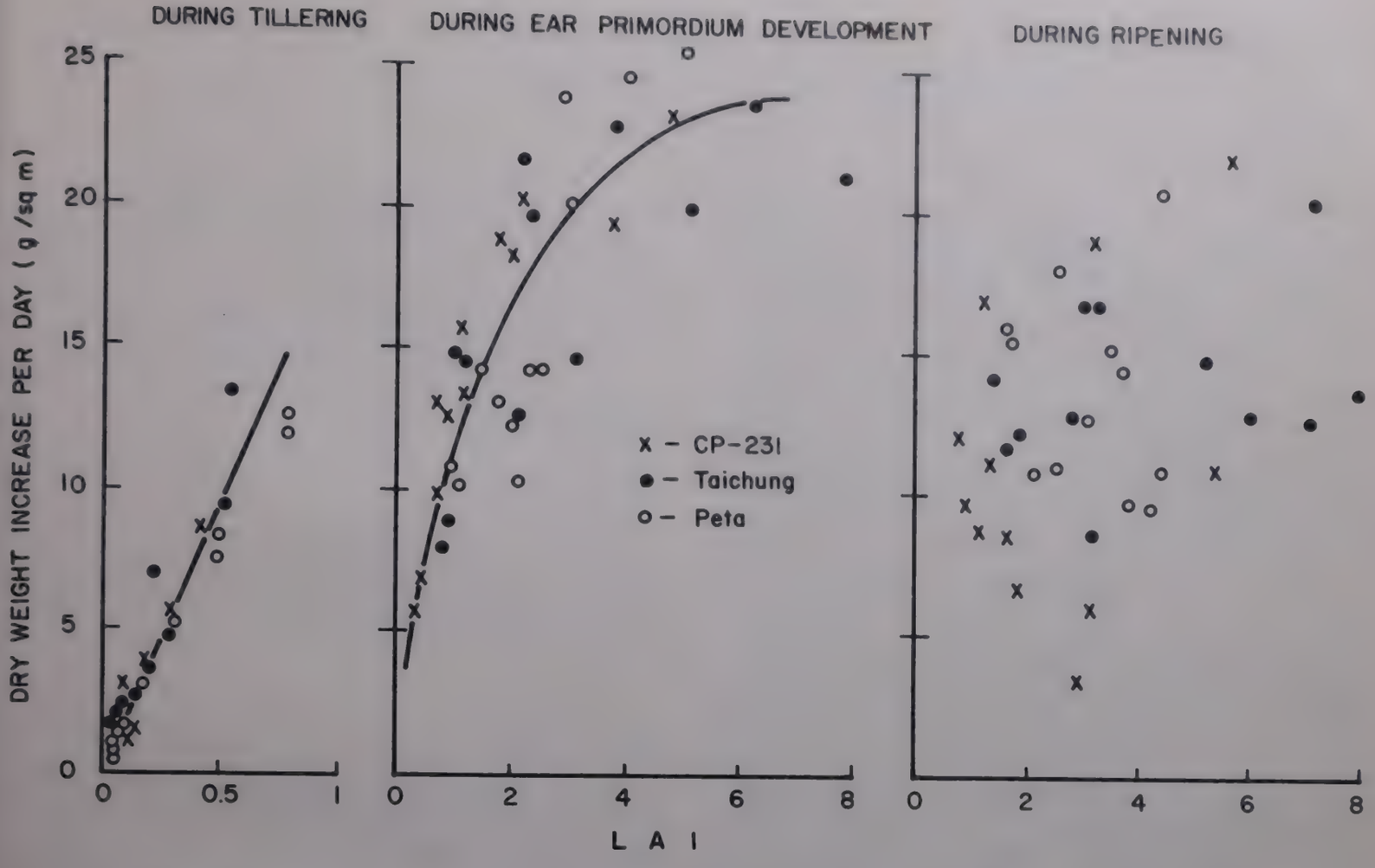


Figure 2.20. Leaf area index vs. dry weight increase per day for three varieties, IRRI, 1962-63 dry season.

High-nitrogen-response varieties have a closer optimum spacing than low-response varieties. Fewer plants per hill at closer spacings or several plants per hill at wider spacings are favorable, especially at a high nitrogen level. The effect of nitrogen on yield is greater at wide than at close spacings, especially with low-nitrogen-response varieties. Varietal differences in nitrogen response are more prominent at close spacings.

The panicle number per unit area increases and the panicle size decreases with a higher application of nitrogen, with reductions in space, and with a larger number of plants per hill.

The leaf area index increases with nitrogen level or a decrease in spacing. Changes in the leaf area index primarily result from the changes in tiller number and, to a smaller extent, from changes in area per leaf.

There is a negative logarithmic relationship between the leaf area index and the light transmission ratio. However, the extinction coefficient of Peta was greater than that of the other varieties, indicating that low-nitrogen-response varieties have large extinction coefficients.

The efficiency of leaves in producing grain is higher in Peta when the leaf area index is small, and it may become negative when it reaches a critical point. The critical point of Taichung 1 was higher than that of Peta probably because of differences in the extinction coefficient.

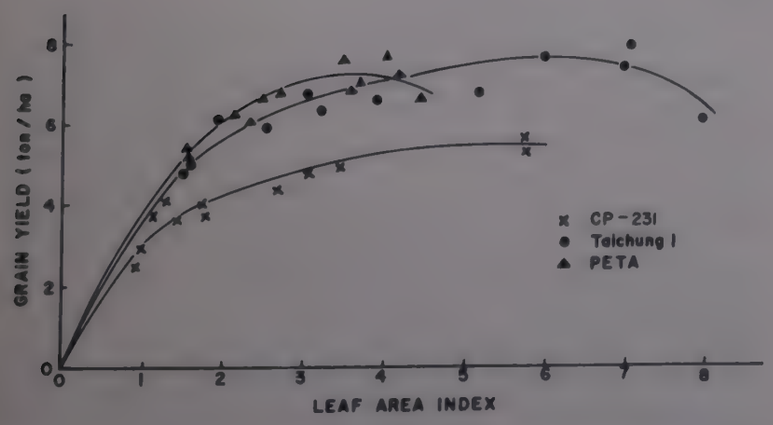


Figure 2.21. Yield vs. leaf area index for three varieties, IRRI, 1962-63 dry season.

Reaction of High- and Low-Nitrogen-Response Varieties to Nitrogen at Different Spacings in Different Seasons (Experiment 9)

Results of experiment 8 revealed a variety x nitrogen level x spacing interaction and indicated a greater nitrogen response in the dry than in the wet season.

To obtain more information about interactions among variety, nitrogen level, spacing, and season, a series of nitrogen level experiments was continued using Tainan-3 and Peta in the dry season as well as in the wet season, with a spacing variable superimposed.

Method

Tainan-3 and Peta were planted in the same field used for experiment 6. Seeds were sown and transplanted on November 12 and December 2, 1962, in the dry season, and on May 15 and June 5, 1963, in the wet season, respectively. Seedlings were transplanted at 25 x 25 and 50 x 50 cm apart, with one plant to a hill. To reduce the residual effect of the previous crop, the straw was cut as low as possible and was removed from the field before plowing. Seventeen kg/ha of P and 33 kg/ha of K and five levels of nitrogen — 0, 30, 60, 90, and 120 kg/ha of additional N as ammonium sulfate — were applied uniformly just before the final puddling. The layout of this series was the same as that of experiment 6.

Samples were taken 50 days after transplanting in the dry season and 40 days after transplanting in the wet season, and at flowering and at harvest in both seasons. The dates of flowering were February 15 and February 28 in the dry season, and August 8 and September 10 in the wet season for Tainan-3 and Peta, respectively. In the dry season, both varieties were harvested March 27; in the wet season, Tainan-3 and Peta were harvested September 17 and October 8, respectively.

It generally was cooler in the dry season than in the wet season especially at the early stages of growth (Table 2.26). Solar radiation from transplanting to ear-initiation was somewhat less in the dry season than in the wet season, but the radiation after flowering was higher during the dry season.

Table 2.26. Average Air Temperatures and Solar Radiation per Day during the 1962-63 Dry Season and the 1963 Wet Season, IRRI[a].

Season	Transplanting to ear-initiation		Ear-initiation to flowering		Flowering to harvest	
	Tainan-3	Peta	Tainan-3	Peta	Tainan-3	Peta
Temperature (° C)						
1962-63 Dry	24.4	24.1	23.9	24.3	25.6	26.1
1963 Wet	27.4	27.3	27.1	26.8	27.1	27.2
Solar Radiation (cal/cm²/day)						
1962-63 Dry	271	273	294	368	456	456
1963 Wet	333	346	346	306	324	325

[a] Data supplied by Weather Station, College of Agriculture, University of the Philippines, Los Baños, Laguna.

Results

Grain Yield

In the dry season the yields of both varieties at both spacings increased with increases in nitrogen level from 0 to 120 kg/ha N (Fig. 2.22). With no additional nitrogen, the yield of Peta was greater than that of Tainan-3.

For Tainan-3 in the wet season, the optimum nitrogen level at 25 x 25 cm was 60 kg/ha and that at 50 x 50 cm was 120 kg/ha. The maximum yield for Peta was obtained with no additional nitrogen at 25 x 25 cm and with 30 kg/ha N at 50 x 50 cm. With no additional nitrogen, the yield of Peta was smaller than that of Tainan-3.

It is apparent that the nitrogen level resulting in maximum yield varies from season to season. The optimum nitrogen level is far higher in the dry than in the wet season.

The optimum level was lower for Peta than for Tainan-3, and was lower at a close than at a wide spacing. The optimum spacing for Peta was wider than that for Tainan-3. The grain yield of Tainan-3 was about the same in each season, but the yield of Peta was lower in the wet season.

Height, Tiller Number, and Ratios of Various Organs

Peta is a tall and actively tillering variety. The percentages of effective tillers and the panicle-straw ratio of Peta were smaller than those of Tainan-3 (Table 2.27).

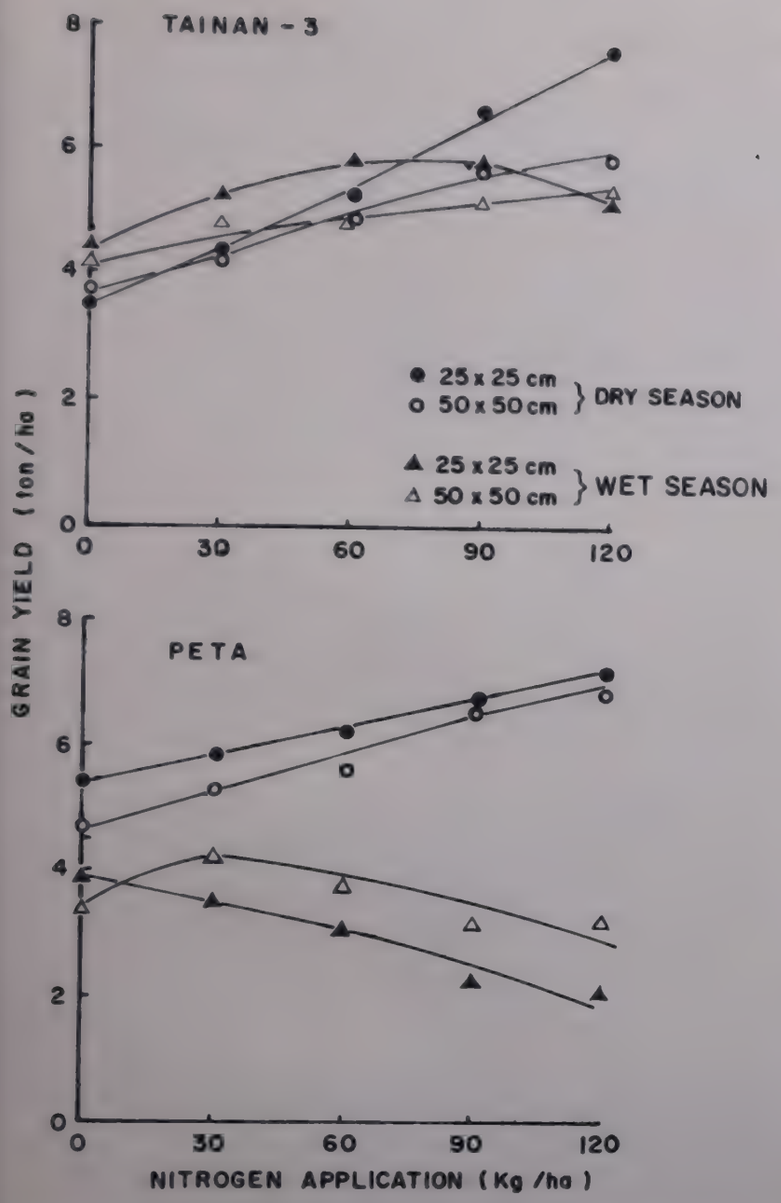


Figure 2.22. Grain yield of Tainan-3 and Peta at two spacings and five nitrogen levels, IRRI, 1962-63 dry and 1963 wet seasons.

With the increase of nitrogen level, the height and the maximum tiller number increased and the percentage of effective tillers and the panicle-straw ratio decreased. At a close spacing, the height at harvest was lower, the maximum tiller number greater; and the percentage of effective tillers and the panicle-straw ratio less than at a wide spacing.

In the wet season, the plants were taller, the maximum tiller number bigger, and the percentage of effective tillers and the panicle-straw ratio smaller than in the dry season. These changes, caused by the difference in seasons, were more prominent in Peta than in Tainan-3.

Internodes elongated more with heavy nitrogen application (Table 2.28). At a close spacing there were more elongated internodes, and those at the lower positions were longer; but those at the top were longer at a wide spacing.

In the wet season, internode elongation was greater in number and in length. Peta had more and longer elongated internodes than Tainan-3, especially in the wet season.

The lodging was more serious in Peta than in Tainan-3, at a close spacing than at a wide spacing. and similarly, in the wet season than in the dry season. The lodging was apparently accelerated by the elongation of the lower internodes.

Leaf Area Index (LAI) and Its Components

LAI increased with increases in nitrogen level. It was bigger at a close than at a wide spacing. The LAI of Peta was bigger than that of Tainan-3. LAI was bigger in the wet than in the dry season, especially in Peta (Table 2.29).

The tiller number increased with increases in nitrogen level. It was bigger at a close than at a wide spacing, and similarly, in the wet than in the dry season. Peta had more tillers than Tainan-3. The average leaf number per tiller was almost constant. The average leaf area increased with increases in nitrogen level. Peta had bigger leaves than Tainan-3. Leaves were bigger in the wet than in the dry season, especially in Peta.

There were positive correlations between the LAI and the tiller number per unit field area and also between the LAI and the average leaf area, but there was no relation between the LAI and the average leaf number per tiller (Fig. 2.23).

Table 2.27. Height, Maximum Tiller Number, Percentage of Effective Tillers, Panicle-Straw Ratio of Tainan-3 and Peta at Two Spacings and Five Nitrogen Levels, IRRI, 1962-63 Dry and 1963 Wet Seasons.

	Nitrogen level (kg/ha)					Spacing (cm)		Variety	
Season	0	30	60	90	120	25 x 25	50 x 50	Tainan-3	Peta
Height (cm)									
Dry	120	123	128	136	141	126	134	123	135
Wet	160	171	178	178	183	173	174	147	203
Maximum tiller number per sq m									
Dry	136	171	203	244	254	250	153	167	236
Wet	184	261	284	284	312	334	193	199	320
Effective tiller percentage									
Dry	93	87	80	80	80	79	89	91	78
Wet	81	78	78	74	67	69	83	93	59
Panicle-straw ratio									
Dry	1.13	1.12	1.07	1.00	0.99	0.96	1.18	1.18	0.96
Wet	0.91	0.84	0.81	0.88	0.83	0.80	0.92	1.20	0.52

Table 2.28. Length of Internodes and Thickness of Culm of Tainan-3 and Peta at Two Spacings and Five Nitrogen Levels, IRRI, 1962-63 Dry and 1963 Wet Seasons.

Season	Position	Nitrogen level (kg/ha)					Spacing (cm)		Variety	
		0	30	60	90	120	25 x 25	50 x 50	Tainan-3	Peta
	Length of elongated internode (cm)									
Dry	Panicle-1 [a]	39	40	40	40	39	37	42	40	39
	1-2	23	23	24	24	26	23	26	24	25
	2-3	16	14	16	18	17	16	16	12	20
	3-4	7.5	11	11	13	13	12	5.3	7	15
	4-5	2.3	3.3	4.2	5.0	6.1	5.2	1.9	1.7	6.5
	5-6	—	1.4	1.6	1.9	2.4	2.0	— [b]	—	3.1
	6-7	—	—	—	—	—	1.0	—	—	1.2
Wet	Panicle-1	36	42	42	41	46	40	42	46	37
	1-2	27	24	23	24	28	24	26	24	26
	2-3	18	20	20	21	21	21	19	15	25
	3-4	15	17	16	16	17	16	15	8.4	23
	4-5	11	10	10	13	12	11	10	3.1	18
	5-6	3.5	5.0	6.5	8.2	8.2	7.3	4.4	—	12
	6-7	1.5	2.3	2.8	4.5	4.5	3.7	2.1	—	5.8
	7-8	—	1.0	1.0	1.7	1.0	2.1	—	—	2.1
	Thickness of the main stem at the base (mm)									
Dry		7.0	7.0	7.4	7.5	7.4	6.8	7.6	6.9	7.5
Wet		6.2	6.0	6.1	6.0	6.1	5.4	6.1	5.4	6.1

[a] Node number counted from the top.
[b] Internode shorter than 1 cm is not recorded.

Table 2.29. Leaf Area Index and its Components of Tainan-3 and Peta at Two Spacings and Five Nitrogen Levels, IRRI, 1962-63 Dry and 1963 Wet Seasons.

Season	Nitrogen level (kg/ha)					Spacing (cm)		Variety	
	0	30	60	90	120	25 x 25	50 x 50	Tainan-3	Peta
	Leaf area index (LAI)								
Dry	1.59	1.84	2.37	3.23	4.21	3.03	2.25	2.25	3.04
Wet	2.83	3.84	4.53	5.41	6.57	5.35	3.97	3.49	5.80
	Tiller number per sq m								
Dry	121	153	177	208	221	202	141	158	185
Wet	147	177	181	220	253	230	175	188	217
	Leaf number per tiller								
Dry	4.0	4.0	4.0	4.1	4.4	3.8	4.3	4.1	3.9
Wet	4.4	4.4	4.4	4.3	4.2	4.3	4.5	4.5	4.3
	Average leaf area (cm^2)								
Dry	32	33	37	39	42	36	37	33	40
Wet	44	51	53	57	56	54	49	41	66
	Thickness of leaves (mg/cm^2)								
Dry	5.53	5.87	5.61	5.35	5.24	5.41	5.64	5.81	5.24
Wet	5.41	5.27	5.33	5.13	5.08	4.93	5.54	5.49	4.98
	Extinction Coefficient (K)								
Dry	0.75	0.84	0.76	0.68	0.59	0.75	0.89	0.59	0.85
Wet	0.32	0.33	0.30	0.34	0.37	0.38	0.29	0.33	0.33

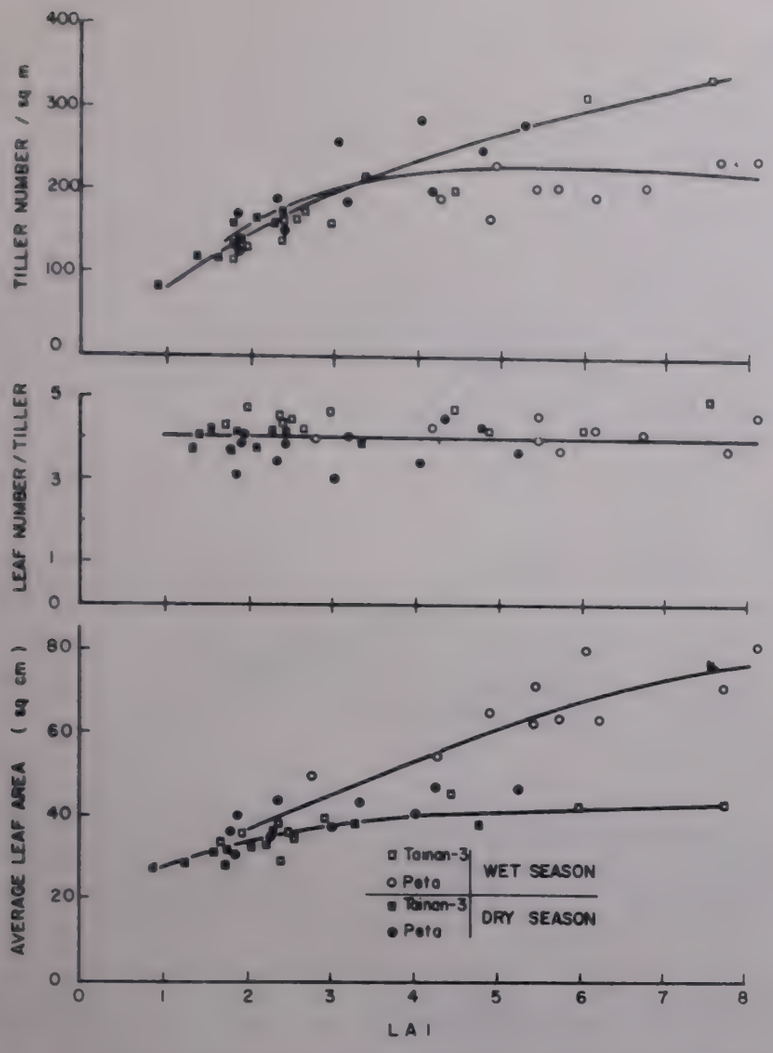


Figure 2.23. Relation between the leaf area index and tiller number, number of leaves per tiller and average leaf area of Tainan-3 and Peta at two spacings and five nitrogen levels, IRRI, 1962-63 dry and 1963 wet seasons.

The increase in LAI was the result of an increase in tiller number and also in average leaf area. The increase of LAI of Peta above 4 was mainly caused by the increase of average leaf area, whereas the increase of Tainan-3 was caused by the increase of tiller number.

There was a positive correlation between the nitrogen content of straw and the relative leaf expansion rate ($\frac{\log e\ LAI_2 - \log e\ LAI_1}{t_2 - t_1}$, where LAI_1 and LAI_2 are the LAI at t_1 and t_2) (Fig. 2.24). However, the data of Peta at a close spacing at high nitrogen levels did not fit the correlation. These could be explained by the fact that if the LAI was above 4, the rate decreased with the increase in LAI.

Generally speaking, there was a relation between the LAI and the light transmission ratio (I/I_0). However, the extinction coefficient (K) was not a constant value. The K in the dry season decreased with increases in nitrogen level (Table 2.29). It was bigger at a wide than at a close spacing, and similarly, in the dry than in the wet season. It seems that the K decreased with the increase in LAI. However, the K value of Peta was bigger than that of Tainan-3, although the LAI of Peta was bigger than that of Tainan-3.

The leaves were thinner at high than at low nitrogen levels, at a close than at a wide spacing, and similarly, in the wet season than in the dry season. Tainan-3 had thicker leaves than Peta.

Percentage of Nitrogen and Absorption

The percentage of nitrogen in the straw was higher at high than at low nitrogen levels and at a wide than at a close spacing (Table 2.30). These differences became smaller with growth. The percentage of nitrogen was higher in the wet than in the dry season at the early growth stages, but there was almost no difference at the later growth stages. At the early growth stages the percentage of nitrogen of these two varieties was almost the same, but at the later growth stages, the percentage of Tainan-3 was higher.

There was no correlation between grain yield and the percentage of nitrogen in the straw at any growth stage (Fig. 2.25).

The amount of nitrogen absorbed by the plants was more at high than at low nitrogen levels, at a close than at a wide spacing. It was more in the wet than in the dry season and also more in Peta than in Tainan-3. These differences were greater at the early growth stages.

Peta absorbed nitrogen more actively than Tainan-3 at the early growth stages, and the varietal difference became less at the later growth stages.

These data indicated that Peta in the wet season at close spacing with heavy nitrogen application absorbed nitrogen actively at the early growth stages. The active nitrogen uptake caused vigorous tillering and leaf expansion. In addition to the big LAI, due to the big K value, the light transmission ratio became extremely low from the early growth stages and nitrogen uptake at the later growth stages was retarded.

Leaf Area Index and Dry Matter Production

At the early growth stages when LAI was small, the dry matter production was proportional to

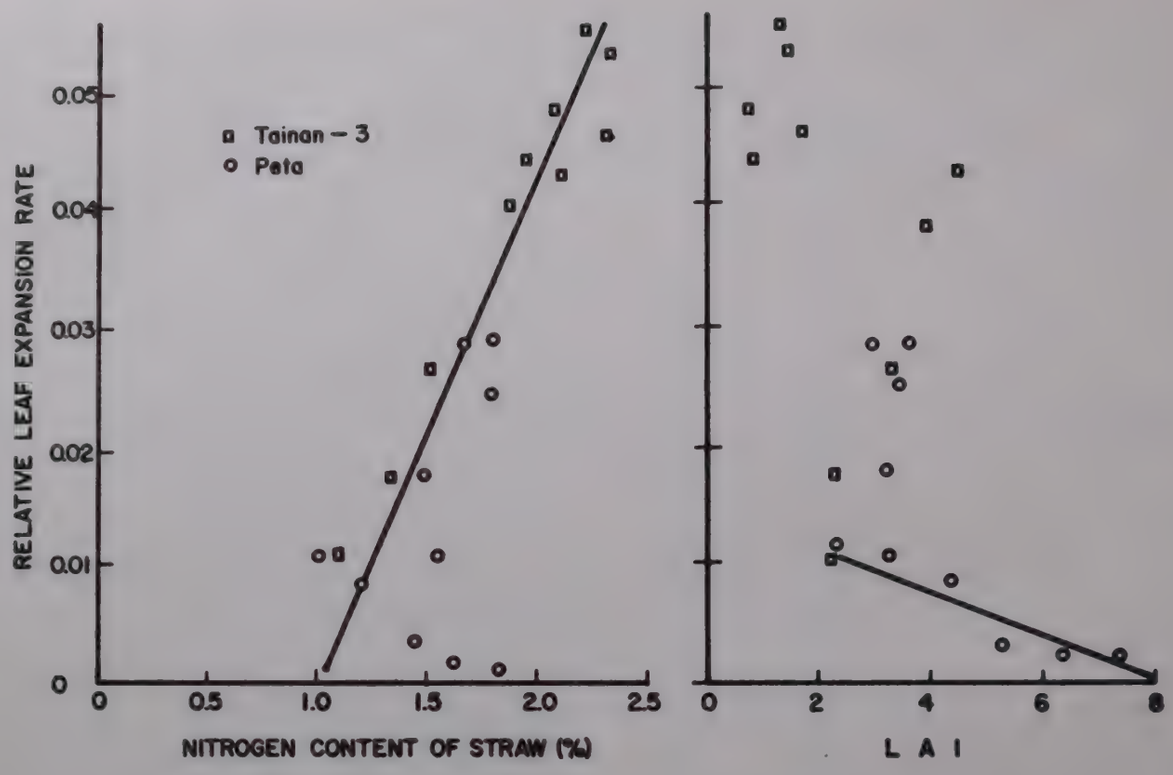


Figure 2.24. Relation of the relative leaf expansion rate to nitrogen content of straw and LAI of Tainan-3 and Peta, IRRI, 1963 wet season.

LAI. However, when LAI became more than 2, the increase in LAI did not accompany the proportional increase in dry matter production (Fig. 2.26).

The net assimilation rate (NAR $= \frac{W_2-W_1}{t_2-t_1} \times \frac{\log e\, LAI_2-\log e\, LAI_1}{LAI_2-LAI_1}$, where W_1 and W_2, LAI_1 and LAI_2 are the weight and LAI at t_1 and t_2,

Table 2.30. Percentage of Nitrogen of Straw and Amount of Nitrogen Absorbed by Tainan-3 and Peta at Two Spacings and Five Nitrogen Levels, IRRI, 1962-63 Dry and 1963 Wet Seasons.

Growth Stage	Season	Nitrogen level (kg/ha)					Spacing (cm)		Variety	
		0	30	60	90	120	25 x 25	50 x 50	Tainan- 3	Peta
Percentage of nitrogen of straw										
Maximum Tiller No.	Dry	1.73	1.76	1.95	2.15	2.32	1.59	2.37	1.92	2.03
	Wet	1.93	2.28	2.51	2.73	2.82	2.15	2.77	2.50	2.43
Flowering	Dry	0.83	0.95	0.94	1.07	1.16	0.84	1.15	1.12	0.87
	Wet	0.75	0.83	0.94	1.01	1.18	0.82	1.07	1.20	0.69
Harvest	Dry	0.43	0.44	0.40	0.40	0.44	0.41	0.41	0.45	0.37
	Wet	0.45	0.44	0.52	0.52	0.60	0.45	0.59	0.61	0.43
Nitrogen absorbed (kg/ha)										
Maximum Tiller No.	Dry	18	29	40	55	61	55	27	35	47
	Wet	30	45	56	67	81	77	35	47	65
Flowering	Dry	43	56	66	88	97	73	69	61	93
	Wet	55	78	100	114	135	107	87	87	107
Harvest	Dry	56	71	75	90	104	84	73	74	87
	Wet	78	93	113	108	134	114	97	106	103

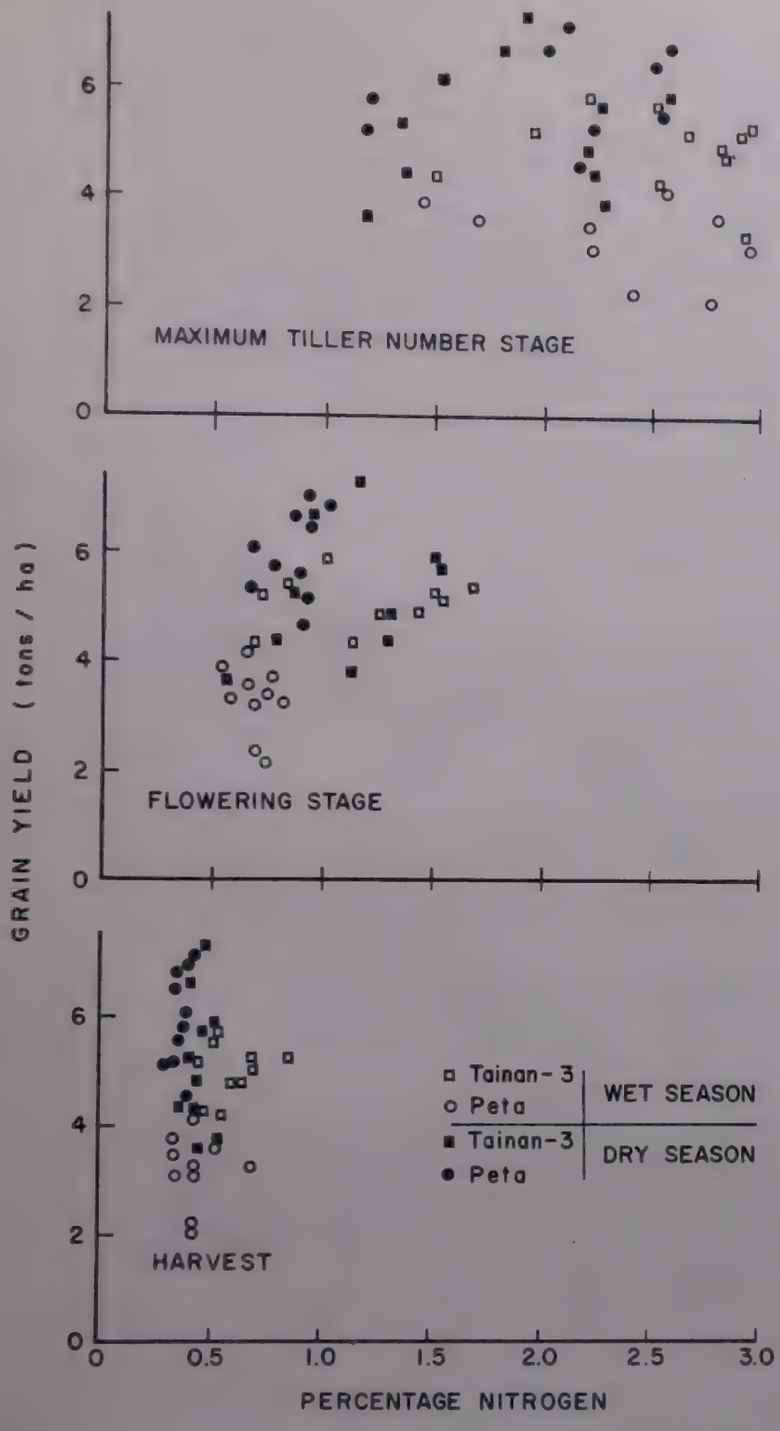


Figure 2.25. **Relation between grain yield and nitrogen percentage of straw at various growth stages of Tainan-3 and Peta, IRRI, 1962-63 dry and wet seasons.**

respectively) was more closely correlated with LAI than with the nitrogen content of straw (Fig. 2.26).

At the early growth stages, there was almost no mutual shading. However, application of nitrogen increased the LAI and dry matter production. At the late growth stages with heavy nitrogen application, the LAI exceeded a certain limit and caused a decrease of NAR. Thus, many excess tillers and many lower leaves died. The development of the ear-primordium was not proportional to the straw weight because of the big LAI at this growth stage. The more the tillers, the smaller the panicle-straw ratio. This was apparently caused by the lower percentage of effective tillers and excessive tiller production at the early growth stages (Fig. 2.27).

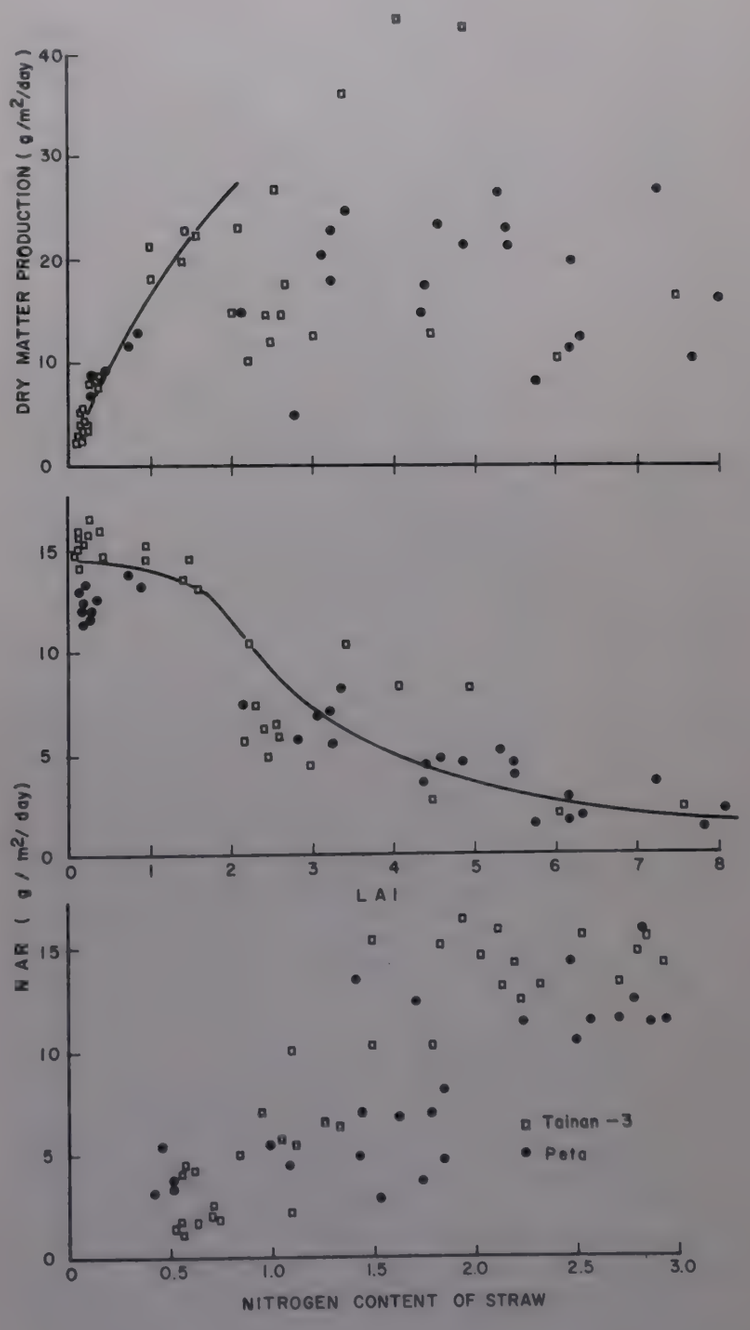


Figure 2.26. **Relation between leaf area index (LAI) and dry matter production and between net assimilation rate (NAR) and LAI and nitrogen content of straw in Tainan-3 and Peta, IRRI, 1962-63 dry and wet seasons.**

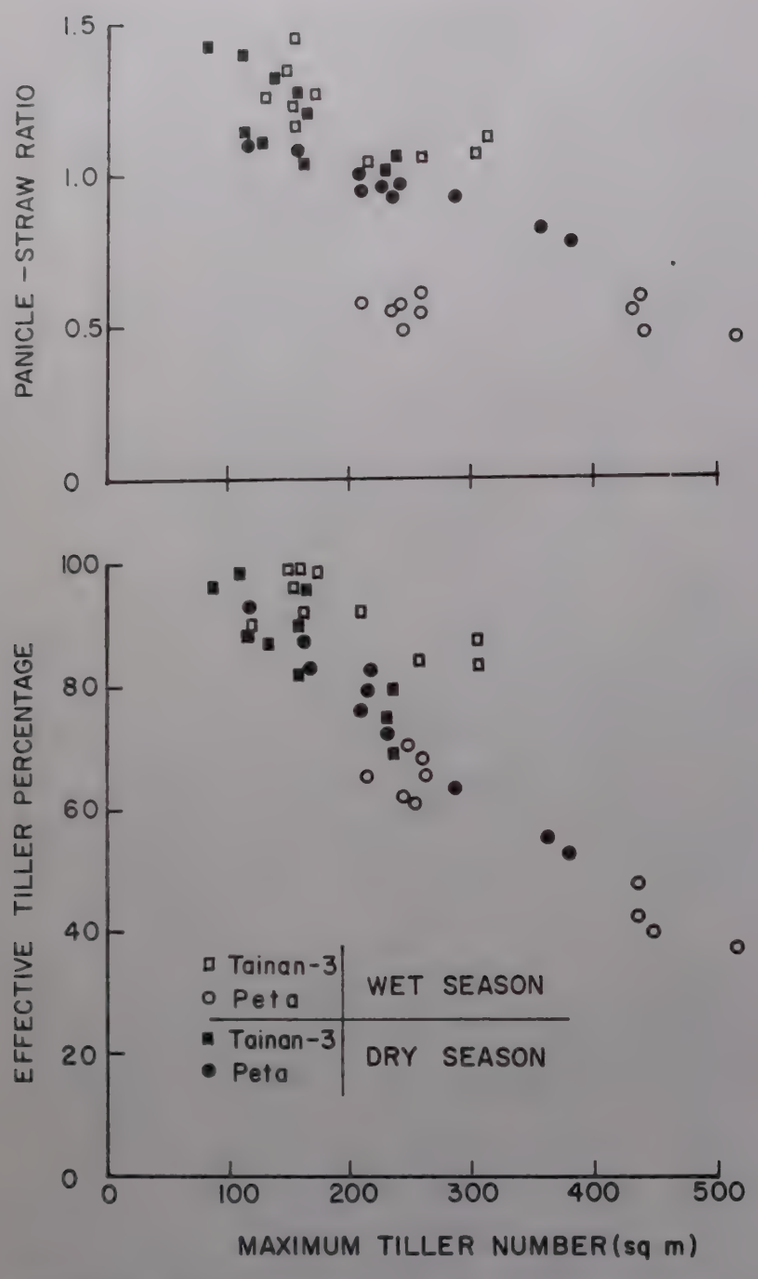


Figure 2.27. **Relation of maximum tiller number to panicle-straw ratio and effective tiller percentage in Tainan-3 and Peta, IRRI, 1962-63 dry and 1963 wet seasons.**

Grain Yield and Leaf Area Index

There was a correlation between LAI and total plant weight. The bigger the LAI, the bigger the total plant weight. However, the bigger total plant weight was not necessarily correlated with the bigger grain production (Fig. 2.28).

In the dry season, the bigger the LAI at flowering, the more the grain production. In this season, the solar radiation during the ripening period was high and the low light transmission ratio at a large LAI did not make grain production difficult.

In the wet season, the solar radiation was limited. The big LAI caused mutual shading

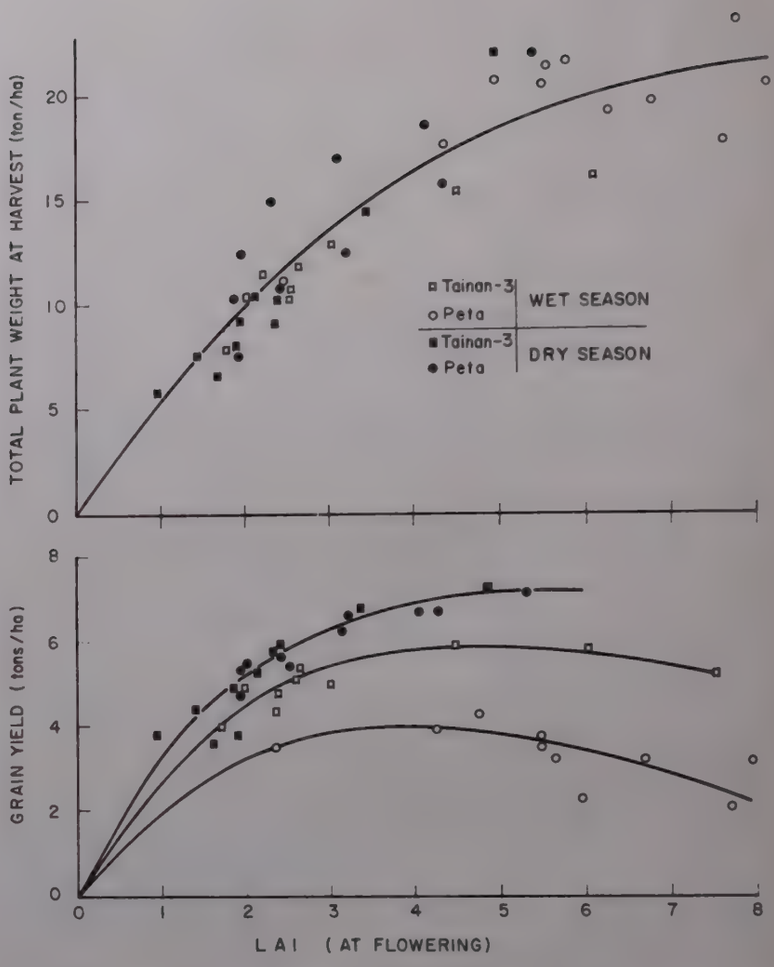


Figure 2.28. **Relation of leaf area index (LAI) to total plant weight and grain weight in Tainan-3 and Peta, IRRI, 1962-63 and 1963 wet seasons.**

which resulted in an unfavorable balance between photosynthesis and respiration. Because of the small K value, the unbalance was not so destructive for Tainan-3, but was a problem for Peta.

Summary

The air temperature was lower in the dry season (24-26°C) than in the wet season (27°C). The solar radiation during ripening was more in the dry season (450 cal/cm²/day) than in the wet season (325 cal/cm²/day).

The optimum nitrogen level is higher for Tainan-3 than for Peta, at a wide spacing than at a close spacing, and in the dry season than in the wet season.

The optimum spacing is wider for Peta than for Tainan-3, at a high than at a low nitrogen level, and in the wet than in the dry season.

In Peta, with high nitrogen level at close spacing in the wet season, nitrogen uptake at early growth stages is vigorous, tillering is active, and LAI becomes large.

When LAI is small, the growth rate is the function of LAI. However, above LAI = 2, NAR becomes an important factor.

The LAI is affected by tiller number per unit area, average leaf number per tiller and average leaf area. The change in LAI is the result of the changes in tiller number and average leaf area. In Peta the average leaf area has a big influence on LAI, and in Tainan-3 the tiller number was a big influence.

The LAI above a certain limit causes a decrease in NAR. Such an LAI is reached at the growth stage when the ear-primordium is growing. Many tillers start to die at this growth stage, and the percentage of effective tillers becomes low and the panicle-straw ratio small.

If the solar radiation is big and the extinction coefficient of the leaves is small, a big LAI is not a serious problem; but with a limited radiation and a big extinction coefficient, the big LAI interferes with grain production.

Discussion

Nitrogen is necessary for plant growth. Increased absorption of nitrogen results in more vigorous plant growth. In the rice plant, an increase of nitrogen uptake results in increased tillering, increased number and size of leaves, and increased height. The plant grows tall and leafy. But, beyond a certain limit, the increase in weight of grain produced generally does not parallel the increase in straw which results from an increase in nitrogen uptake.

Mutual Shading and Nitrogen Response

When different rice varieties are grown under conditions in which plants are isolated from each other and each plant receives sufficient sunshine, the grain yield increases with an increase in nitrogen. Varieties differ in their response to nitrogen under such conditions. Varieties that respond with greater increases in grain yield absorb and metabolize nitrogen more vigorously than other varieties. They produce more tillers, more leaves, bigger roots, and more grain; they use the absorbed nitrogen efficiently.

If these varieties are planted in the field at conventional spacing, especially in the rainy season in the tropics, the increase in foliage resulting from heavy nitrogen application produces serious mutual shading and adversely affects grain yield.

The low-nitrogen-response varieties use assimilation products efficiently to absorb nitrogen and to expand plant body instead of storing these products as starch (Tanaka *et al.*, Part I of this bulletin). As a result, the increase in nitrogen application remarkably increases dry matter production, height of the plant, and foliage expansion.

There is a negative logarithmic relation between the leaf area index (LAI) and the light transmission ratio (LTR). A big LAI results in a proportional reduction in light intensity in the plant population (Monsi and Saeki, 1953). Varieties with more tillers have a bigger LAI. As typical *indicas* tiller more actively than *japonicas,* their nitrogen response is less than that of the *japonicas.* But some *indicas* have tillering habits similar to *japonicas;* these respond well to nitrogen.

It has been stated that *panicle number* types respond to nitrogen better than *panicle weight* types (Baba, 1961). This is the case only when nitrogen application is limited. With heavy nitrogen application, panicle number types suffer more than panicle weight types because of mutual shading. But some varieties produce many tillers and possess a big LAI; because of short stature and erect leaf character, the extinction coefficient (K) is small and the leaves do not produce a proportional decrease in LTR. For this reason, some of the panicle number type varieties respond well to nitrogen.

These exceptions indicate that *indicas* are not necessarily low-nitrogen-response varieties (Report, 8th Meeting, Working Party on Soils, Water and Fertilizer Practices, IRC, 1961).

During the rainy season in the tropics, solar radiation is less. Plants grow tall and leafy because of higher temperature and less sunshine. Plants in the field suffer from a shortage of light more seriously in the rainy season than in the dry season. These may be some of the reasons why applied nitrogen affects grain production less in the rainy than in the dry season.

Spacing and Nitrogen Response

If mutual shading is the factor limiting nitrogen response, the response can be improved by increasing the spacing.

Spacing, like nitrogen, is an important factor in the yield of various crops (Holliday, 1960). As rice plants tiller more actively than other crops,

the relationship between the grain yield of the rice plant and spacing differs from that of other crops. There is a logarithmic relation between population and production of total dry weight per unit area. But the grain weight per unit field area increases with the decrease in spacing up to a certain extent, after which there is either a decrease or hardly any change; this depends on the variety (Kanda and Kakizaki, 1957).

The number of panicles per unit area increases and the weight per panicle decreases with a decrease in spacing (Yamada, 1961).

The relationship between yield and spacing is complicated. As a rule, under less favorable conditions, closer spacing and planting of several plants per hill is recommended (Nagai, 1962). In southern Japan where the temperature is higher than in northern Japan, wider spacing is used (Matsuo, 1952). The optimum spacing at low nitrogen levels is closer than that at high nitrogen levels (Hoshino, Kakimoto, and Satake, 1957). Lodging occurs earlier at closer spacing. An increase in spacing decreases lodging (Cruz and Tilo, 1956). For this reason, wide spacing is recommended for varieties that lodge (Samad, Chandramohan, and Vijayan, 1956). The optimum spacing is closer for low-tillering as compared with that for high-tillering varieties (Uichanco, 1959), and for the short-duration as compared with long-duration varieties (Ghose, Ghatge, and Subrahmanyan, 1960).

The changes resulting from changes in spacing indicate that, at close spacing with heavy nitrogen application, mutual shading becomes more serious, especially with low-nitrogen-response varieties.

Spacing experiments reported here demonstrate that, under ordinary field conditions, plants compete for light at an earlier growth stage than they do for nitrogen.

Various interactions demonstrate the relationships among variety, nitrogen level, spacing, number of plants per hill, and season. Low-response varieties have a wider optimum spacing than high-response varieties. The optimum spacing is wider in the rainy than in the dry season and at high than at low nitrogen levels. The optimum number of plants per hill is more at wide than at close spacing.

Nitrogen response is more remarkable at wide than at close spacing, with fewer than with more plants per hill, and similarly, in the dry than in the rainy season.

It also was demonstrated that even at wide spacing, serious mutual shading resulting from heavy nitrogen application cannot be avoided. Low-nitrogen-response varieties produce many tillers (as many as 100 per hill) at wide spacing with heavy nitrogen application. Only a few tillers located outside the hill receive light, but the outside tillers shade those inside the hill.

Yield Components

Nitrogen application affects each yield component. Generally, with an increase in nitrogen, the panicle number per unit area and the number of spikelets per panicle increase and the percentage of filled grain and 1,000-grain weight decrease. The panicle number per unit area is decided by two factors, i.e., the maximum tiller number and the effective tiller percentage. With an increase in nitrogen, the maximum tiller number increases but the percentage of effective tiller decreases.

There is a particular growth stage when each component is decided, and the sequence is as follows: maximum tiller number, percentage of effective tillers, spikelet number per panicle, percentage of filled grains, and 1,000-grain weight.

Mutual shading is the major determinant of varietal differences in nitrogen response. The effect of nitrogen level on each yield component differs between low- and high-response varieties depending upon the growth stage when serious mutual shading begins.

Low-response varieties at high nitrogen levels actively tiller and have a big maximum tiller number. However, because of active tillering, serious mutual shading occurs at an early stage of growth, and the percentage of effective tillers becomes extremely low. Thus, with increased nitrogen, there is almost no increase in panicle number (Oka, 1956).

The reduction of the percentage of effective tillers does not eliminate serious mutual shading completely; thus the spikelet number per panicle also decreases, and the percentage of filled grains tends to decrease under some conditions.

When the field becomes crowded at about the ear-initiation stage, the weight per panicle decreases remarkably. After ear-initiation, the internodes elongate and the ear-primordium deve-

lops. During this period the need of the plants for carbohydrates increases, and, if the field is overcrowded, the accumulation of carbohydrates cannot catch up with the requirement; the plants become abnormal (Tanaka, 1958a). As a result, the number of spikelets per panicle and the percentage of filled grains decrease. Because of this decrease in yield components, the grain number per unit field area is adjusted to the number which is just adequate to store substances produced by the plant. Consequently, only a small or no decrease at all of 1,000-grain weight is observed with an increase in nitrogen (Baba, 1961).

Where serious mutual shading sets in at later stages of growth rather than at the early ear-primordium differentiation stage, the decrease in the percentage of filled grains or 1,000-grain weight is the major cause of grain yield decreases associated with heavy nitrogen applications. This general principle applies in the case of high-nitrogen-response varieties under some conditions, or low-response varieties under special conditions.

The most prominent difference in the change of yield components by nitrogen application between low- and high-nitrogen-response varieties is the difference in changes in the panicle number. Low-nitrogen-response varieties show a limited or negligible increase in panicle number, whereas high-response varieties exhibit a big increare with an increase in nitrogen. This clearly indicates that the adverse effect of heavy nitrogen application in low-nitrogen-response varieties, i.e., mutual shading, occurs from the early stage of growth, that is, the maximum tiller number stage.

Lodging

Generally low-nitrogen-response varieties are taller and more susceptible to lodging than high-nitrogen-response varieties.

Low-nitrogen-response varieties are leafy, and the resulting mutual shading reduces the light intensity at the base of the plants. Under this condition, elongation of the lower internodes accelerates, and more and longer elongated internodes are produced. This situation is more pronounced with heavy nitrogen applications, and/or close spacing.

If rice plants are planted close to each other and heavy applications of nitrogen are made, the plants become taller, the culms thinner, and the plants top-heavy. These morphological characters increase lodging.

These phenomena indicate that mutual shading is one of the causes of lodging and at the same time the most important factor associated with the decrease in grain yield with heavy nitrogen application. It is apparent that if lodging is serious because of excessive nitrogen application, grain yield decreases. But this does not provide evidence for concluding that lodging is the direct major cause of decreases in grain yield.

Nitrogen Uptake and Metabolism

Low-nitrogen-response varieties actively absorb as well as metabolize nitrogen. With heavy nitrogen application, these varieties at the early stages of growth absorb nitrogen more actively than high-nitrogen-response varieties (Matsuo, 1952; Takahashi, Iwata, and Baba, 1959; Tanaka *et al.*, Part I of this bulletin). An adequate soluble-total nitrogen ratio is maintained during the growth stages when mutual shading is not serious.

The active nitrogen uptake and metabolism are accompanied by a big increase in dry weight, active tillering, and height increase and expansion of leaf area. Thus, serious mutual shading sets in early; and the physiological status of the plants becomes abnormal because of the imbalance between photosynthesis and respiration. Because of this abnormal physiological state, the soluble-total nitrogen ratio increases, nitrogen uptake slows, lower leaves start to die, and, under some circumstances, the plant loses nitrogen. The big soluble-total nitrogen ratio results from mutual shading and not from a weakness in the nitrogen metabolism of low-response varieties.

The root development of low-response varieties is more active than that of high-response varieties. Because of bigger roots, the varieties can absorb more nitrogen from the soil when the nitrogen level in the soil is low. But, if the nitrogen supply is excessive the roots of these varieties become weak because of (a) the active nitrogen uptake which consumes a large amount of carbohydrate and (b) the death from mutual shading of lower leaves which supply assimilation products to roots. With poor root development, the plants are more susceptible to lodging.

Low-nitrogen-response varieties actively absorb and metabolize nitrogen. Because of this active

physiological character, however, the plants produce leaves which are both too large and too numerous when nitrogen is abundant. The plants exhaust all assimilated energy and leave no stored energy. The expansion of leaves results in mutual shading, an imbalance between photosynthesis and respiration, and an acceleration in the utilization of assimilated products.

Mineral Element Content

High-nitrogen-response varieties generally have darker green color than low-response varieties. The high magnesium, manganese, or iron content may be correlated with the darker green color of these varieties. High-nitrorgen-response varieties have high silica content. This is related to the more erect leaf character of the varieties.

Low-response-varieties have a lower percentage of dry matter. This may be related to the soft character of the leaves. The leaves with less silica and less dry matter droop and produce more shade. The potassium content of low-response varieties is higher than that of high-response varieties. This may be related to the high water content.

Leaf Area and Dry Matter Production

The LAI is determined by the tiller number per unit field area, average leaf number per tiller, and average area per leaf. The change in the LAI is the result of the changes in tiller number and average area per leaf, but not in the number of leaves per tiller.

The LAI increases in proportion to the percentage of nitrogen in the plants until the LAI reaches a value of 4. Above LAI = 4, the leaf expansion rate decreases in proportion to the increase in LAI, and at about LAI = 8, no more increase takes place. This indicates a ceiling for the LAI (Kanda and Sato, 1963). The LAI cannot be bigger than the ceiling LAI, which is about 8 (observer maximum is 8.5) under the cultivation conditions of the experiments reported here. The leaves are thinner at high than at low nitrogen levels, at close than at wide spacing, and in the rainy than in the dry season. A reduction in the amount of light supplied to a plant makes the leaves thin. In other words, a bigger leaf area is produced by using a unit amount of material when the light supply is limited. This provides an opportunity to use limited light at a higher efficiency. However, if the LAI reaches a certain level, the bigger LAI caused by thinner leaves may result in more serious mutual shading because of more droopy leaves.

The K value differs with variety. Broadly, varieties with a small K respond to nitrogen better than those with a big K. But various factors can change the K value of a variety. For example, with a decrease in the LAI, K becomes bigger. This indicates that the efficiency of light utilization of a given leaf area increases with a decrease in the LAI.

The self-adjusting nature of the plant makes it difficult to compare varietal character by means of the K value. More detailed studies are needed of the relationships between the K value and various morphological characters, e.g., length, width and thickness of leaves, angle between leaf and culm, plant height.

Dry matter production increases proportionally with the increase in the LAI until the LAI reaches 2, above which the dry matter production is no longer proportional to the LAI increase because of the decrease in the light-receiving coefficient (Murata, Osada, and Iyama, 1957). The net assimilation rate decreases with an increase in the LAI.

Generally, in low-response varieties the grain-straw ratio is small, and this becomes even smaller with heavy nitrogen application. In high-response varieties, the ratio is big, and this increases with increases in nitrogen, up to a certain level of nitrogen.

The grain-straw ratio is closely related to the percentage of effective tillers. As a low percentage of effective tillers is closely related to a bigger maximum tiller number, the grain-straw ratio is partially decided at a rather early stage of growth. Of course it is also affected by the dry matter production after flowering.

The importance of the grain-straw ratio indicates that an understanding of total dry matter production does not completely explain low nitrogen response.

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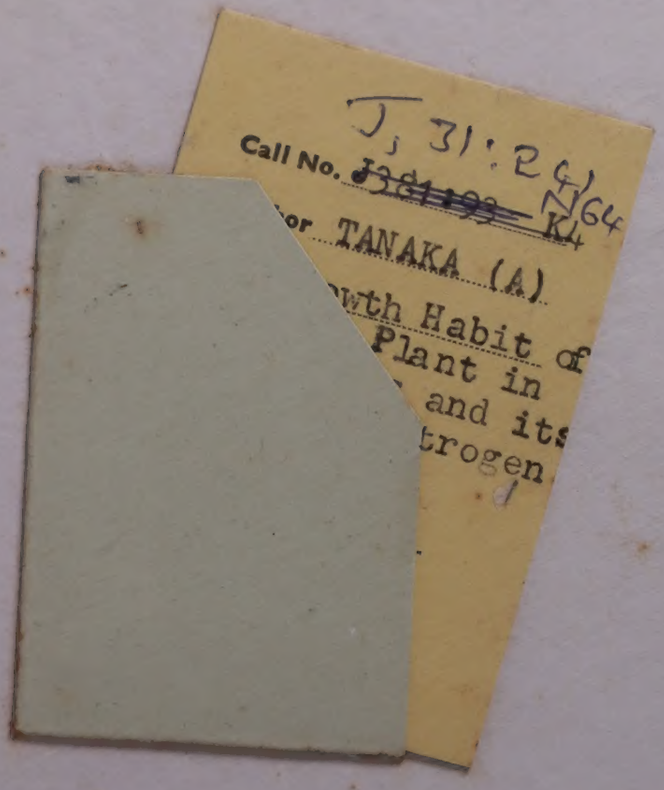
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